Florida Scientist

[illegible]

CONTENTS

[illegible]

Q
11
.F5F63
NH

ISSN: 0098-4590

Florida Scientist

FLORIDA ACADEMY of SCIENCES
1936

Volume 60 Winter, 1997 Number 1

CONTENTS

The Herpetofauna of Buck Island Ranch: An Altered Wetland in South-Central Florida ..... Walter E. Meshaka, Jr. 1
Water Quality Measures on Florida Dairies: Issues of Regulation and Farm Size ..... P. F. Monaghan, M. E. Swisher, and H. H. Van Horn 8
Responses of Two Closely Related Rail Species, *Rallus Longirostris* and *Rallus Elegans,* to Conspecific and Heterospecific Calls ..... Ali M. Rabatsky 16
Studies on Florida Chrysophyceae (Paraphysomonadaceae) and Synurophyceae (Mallomonadaceae). V. The Flora of North-Central Florida ..... Daniel E. Wujek and Peter A. Siver 21
Acknowledgment of Reviewers 27
Water-Soluble Mutagen Production During the Bioremediation of Oil-Contaminated Soil ..... William C. Blodgett, Jr. 28
The First Record of *Artibeus jamaicensis* Leach (1821) from the United States ..... Philip A. Frank 37
Respiratory Stategies of a Non-Native Florida Cichlid, *Cichlasoma octofasciatum* ..... Claire O. Obordo and Lauren J. Chapman 40
An Introduction to the Tides of Florida Bay ..... Ned P. Smith 53

SMITHSONIAN
MAY 16 1997
LIBRARIES

FLORIDA SCIENTIST

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES
Copyright© by the Florida Academy of Sciences, Inc. 1997
Editor: Dr. Dean F. Martin Co-Editor: Mrs. Barbara B. Martin
Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, Florida 33620-5250
Phone: (813) 631-4121; e-mail: Martin@chuma.cas.usf.edu

Business Manager: Dr. Richard L. Turner
Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975
Phone: (407) 768-8000, ext. 8196; e-mail: rturner@fit.edu

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at $40.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

Officers for 1996–1997
FLORIDA ACADEMY OF SCIENCES
Founded 1936

President: Dr. David W. Black
South Florida Water Management District
P.O. Box 24680
West Palm Beach, Florida 33416

President-Elect: Dr. Yasar Iscan

Secretary: Dr. Richard March
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416

Treasurer: Mrs. Georgina Wharton

Executive Secretary: TBA

Program Chairs: Dr. George M. Dooris
and Dr. Patricia M. Dooris
Department of Science and Mathematics
St. Leo College
St. Leo, FL 33574

Published by The Florida Academy of Sciences, Inc.
P.O. Box 033012
Indialantic, Florida 32903-0012
Printing by Allen Press, Lawrence, Kansas

Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

DEAN F. MARTIN, *Editor* BARBARA B. MARTIN, *Co-Editor*

Volume 60 Winter, 1997 Number 1

Biological Sciences

THE HERPETOFAUNA OF BUCK ISLAND RANCH: AN ALTERED WETLAND IN SOUTH-CENTRAL FLORIDA

WALTER E. MESHAKA, JR.

Archbold Biological Station, P.O. Box 2057, Lake Placid, Florida 33862. Present Address:
Museum, Everglades National Park, 40001 SR-9336, Homestead, Florida 33034-6733

ABSTRACT: *Thirty-four reptile and 19 amphibian species were observed or collected from January 1990 to March 1995 on Buck Island Ranch, an altered wetland in Highlands County, south-central Florida. Of eight exotic species established near the ranch, four were found on the ranch and two others were predicted to colonize the ranch. The number of native species was similar to freshwater wetlands and hammocks of the Everglades in southern Florida and the Katharine Ordway Preserve in north-central Florida. Most species were found in ditches, pastures, and ponds, but also in canals, hammocks, buildings, and orange groves. Results of this survey, although qualitative, indicate that habitats of this altered landscape were tolerated at some level by the same herpetofaunal community found in natural analogs of Florida and that there is potential for ranches to support a resilient herpetofauna.*

THE status and conservation of reptiles and amphibians on ranchlands warrants concern in light of potentially large scale alteration of habitat such as forest clearing and drainage associated with that industry. In south-central Florida cattle ranching on large scale has a historical presence by Seminole Indians and White settlers since the 1800s (Tebeau, 1968). In more recent times, drainage of wetlands and conversion of native prairie and other habitats to improved pasture increased the potential for changes in the community structure of reptiles and amphibians. In this paper, I present a list of reptile and amphibian species from a cattle ranch in south-central Florida. I examine the species list with respect to status of, and invasibility by, locally established exotic species and similarity of the herpetofauna to two natural wetland and upland systems so as to evaluate the suitability of a ranch for the conservation of the native herpetofauna.

Materials and Methods—The study site was Buck Island Ranch (BIR), a 4,086-ha cattle ranch located approximately 22 km southeast of Lake Placid, Highlands Co.(T 38S, S2, 9–11, 13–1 6, 21–28, 33–36, R31E). The ranch, in existence since the early 1920s and now the MacArthur Agroecology Research Center of the Archbold Biological Station, is part of the Istokpoga-Indian Prairie Basin, a formerly extensive wetland connecting Lake Istokpoga to the north to Lake Okeechobee to the south. Drainage is accomplished by interconnecting ditches of variable hydroperiod and depths. The Harney Pond Canal (C-41), dug in 1960, crosses east-west through the ranch and borders part of the north and west sections of the ranch.. Major habitats on the ranch (Layne 1993) are improved pasture (48%), marsh and slough (35%), cabbage palm (*Sabal palmetto*)–live oak (*Quercus virginianus*)-dominated hammock (15%), and citrus grove (2%). Live oaks and cabbage palms are widely scattered in pasture as are isolated wetlands which hold water from one to 11 months. Dominant aquatic vegetation of the wetlands was either pickerel weed (*Pontaderia lanceolata*) or soft rush (*Juncus effusus*). Dominant aquatic vegetation of canals was usually water lettuce (*Pistia stratiotes*). Dominant aquatic vegetation of ditches was *P. lanceolata, J. effusus,* water hyacinth (*Eichornia crassipes*), spatterdock (*Nuphar luteum*), or cat-tail (*Typha* spp.). Dominant aquatic vegetation of a 1.2-ha. pond was *J. effusus, N. luteum,* and para grass (*Panicum purpurascens*). Maximum depth of the pond is 5.0 m and it was dug from a wetland in 1970 (Childs, 1996). Nine cottages encircle the south and west part of the pond.

I made opportunistic collections and observations of reptiles and amphibians from January 1990 to March 1995 and conducted a more intensive survey using funnel traps along three water courses from January 1993 to December 1994 while residing on the ranch. Nightly records of anuran chrouses were conducted from October 1993 to September 1994. Records were also provided by ranch hands and visiting researchers. When possible, voucher specimens were deposited in the vertebrate collections of Archbold Biological Station. Faunal comparisons were made with that of the locally established exotic herpetofauna, and with the freshwater, mesic hammock, and building habitats of the Katharine Ordway Preserve-Swisher Memorial Sanctuary, Putnam Co., Florida (Franz, 1995) and Everglades National Park, Dade and Monroe, Co., Florida (Duellman and Schwartz, 1958; Dalrymple,1988; records of the Museum, Everglades National Park, Homestead, Dade County, Florida).

Results and Discussion—I recorded 34 reptile and 19 amphibian species at BIR. Four species were exotic, three of which were restricted to buildings (Table 1). The greenhouse frog (*Eleutherodactylus planirostris*), a successful invader of natural systems in Florida (Dalrymple, 1988), including Lake Placid (Lips and Layne, 1989), was captured and heard calling in hammocks and around buildings. The brown anole (*Anolis sagrei*), also a colonizer of natural systems in Florida and present in Lake Placid since the 1970s (Godley et al., 1981), was found only on one cottage. This colony was not discovered until 1994 and so this species may not yet have had the time and opportunity to disperse to the scattered hammocks. The Indo-pacific gecko (*Hemidactylus garnotii*) and the Mediterranean gecko (*Hemidactylus turcicus*) were primarily found on buildings, although the former species was also found on nearby cabbage palms. During the course of this study, ≥ 8 *H. garnotii* could be seen on any given cottage at night during the summer months whereas only one *H. turcicus* was ever seen on a building and none anywhere else. Replacement by *H. garnotii* might explain the dearth and eventual loss of *H. turcicus* on the ranch as it has in Lake Placid and in other areas of syntopy in Florida (Meshaka, 1995).

Of the seven established exotics in Lake Placid, the braminy blind snake

(*Ramphotyphlops braminus*), the cane toad (*Bufo marinus*), and the Cuban treefrog (*Osteopilus septentrionalis*), were not recorded on the ranch. Seasonal flooding of most of the ranch could preclude or severely limit the colonization of *R. braminus,* a factor not present in Lake Placid where it has been recorded (Meshaka, 1994a). Because potted plants were seldom brought to BIR, there has been little opportunity for its dispersal to BIR.

Bufo marinus could succeed on the ranch unobstructed by potential competitors and predators where it would be a perpetual source of mortality for cattle dogs and naive mammalian predators. A long-established colony is located in a neighborhood in Lake Placid where toads thrive on the irrigated lawns and along the network of canals (Meshaka, Unpubl. data). However, *B. marinus* does not appear able to invade the scrub habitat that surrounds the development, and, like *R. braminus,* it is not apt to disperse free on vehicles. In light of these observations I suggest banning ornamental plants on BIR to curtail opportunity to colonize by *R. braminus* and *B. marinus.*

On the other hand, from what is known of the life history of *O. septentrionalis* in the Everglades (Meshaka, 1994b), its growing presence in Lake Placid (Meshaka, Unpubl. data), and in light of its vagility through various forms of human agency (Meshaka, 1996a), it is only a matter of time before this species colonizes the buildings and hammocks of the ranch; its batracophagous habits (Meshaka, 1994, 1996b) warranting concern. In this connection, one failed attempt at colonization of buildings at BIR from a trailer is reported for this species (Meshaka, 1996a). Presumably, these events are likely to increase in frequency with recent increases in the number of visiting researchers to BIR. The Old World tropical house gecko (*Hemidactylus mabouia*) is also expected to colonize BIR. This species occurs nearby in Palmdale, Glades Co. (Meshaka et al., 1994a), it appears to be highly vagile, and is a good colonizer of buildings where it replaces other hemidactylines (Meshaka et al., 1994b; Meshaka and Moody, 1996). Thus, on BIR, one half of the locally established exotic species of reptiles and amphibians are present, one species (*H. turcicus*) is expected to go extinct, two species can be prevented from reaching the ranch regardless of whether they might (*B. marinus*) or might not (*R. braminus*) succeed, and two species (*O. septentrionalis* and *H. mabouia*) are predicted to colonize.

With the exception of aquatic forms, most of the native herpetofauna of BIR were found in more than one habitat (Table 1) where they exploited a hydrologically patchy environment. The green anole (*Anolis carolinensis*), indigo snake (*Drymarchon corais*), yellow rat snake (*Elaphe obsoleta*), and black racer (*Coluber constrictor*) were routinely seen in all habitats. In contrast, the gopher tortoise (*Gopherus polyphemus*) and gopher frog (*Rana capito*), were, not surprisingly, restricted to the open and sandy margins of an oak hammock and in an adjoining small parcel of scrubby flatwoods in the southwest corner of the ranch.

The most species-rich habitats were ditches, pastures, and the pond (Table 1). The former, with hydroperiods of six to 10 months and water depths

TABLE 1. Reptiles and amphibians found in seven habitats of Buck Island Ranch. * = vouchers. 1 = exotic species. Orange grove fauna is exclusive of ditches.

	Pasture	Hammock	Pond	Canal	Ditch	Grove	Building	Total
Chelydridae								
Chelydra serpentina			x	x	x			3
Emydidae								
Pseudemys floridana			x	x	x			3
Pseudemys nelsoni			x	x	x			3
*Terrepene carolina**		x						1
Kinosternidae								
*Kinosternon baurii**			x	x				2
Kinosternon subrubrum	x							1
Trionychidae								
Apalone ferox			x	x	x			3
Alligatoridae								
Alligator mississippiensis			x	x	x			3
Anguidae								
*Ophisaurus ventralis**	x							1
*Ophisaurus compressus**	x							1
Gekkonidae								
*Hemidactylus garnotii**^{1}							x	1
*Hemidactylus turcicus**^{1}							x	1
Iguanidae								
*Anolis carolinensis**	x	x	x	x	x	x	x	7
*Anolis sagrei**^{1}							x	1
Scincidae								
*Eumeces inexpectatus**	x	x					x	3
*Scincella lateralis**	x	x						2
Colubridae								
*Coluber constrictor**	x	x	x	x	x	x	x	7
Drymarchon corais	x	x	x	x	x	x	x	7
*Diadophis punctatus**	x	x					x	3
*Elaphe guttata**	x					x	x	3
*Elaphe obsoleta**	x	x	x	x	x	x	x	7
*Farancia abacura**			x	x	x			3
*Lampropeltis triangulum**	x							1
*Nerodia fasciata**			x		x			2
*Nerodia floridana**			x	x	x			3
*Opheodrys aestivus**	x	x						2
*Regina alleni**			x					1
*Seminatrix pygea**			x		x			2
*Storeria dekayi**	x							1
*Thamnophis sauritus**			x	x	x			3
*Thamnophis sirtalis**	x				x			2
Viperidae								
*Agkistrodon piscivorus**			x	x	x			3
Crotalus adamanteus	x	x				x		3
*Sistrurus miliarius**	x	x			x			3
Amphiumidae								
*Amphiuma means**			x	x	x			3

TABLE 1. Continued.

	Pasture	Hammock	Pond	Canal	Ditch	Grove	Building	Total
Salamandridae								
*Notophthalmus viridescens**	x		x	x	x			4
Sirenidae								
*Pseudobranchus striatus**			x		x			2
*Siren lacertina**	x		x	x	x			4
*Siren intermedia**			x					1
Bufonidae								
*Bufo terrestris**		x			x			2
Bufo quercicus	x				x			2
Hylidae								
*Acris gryllus**			x	x	x			3
*Hyla cinerea**			x	x			x	3
Hyla gratiosa		x						1
*Hyla femoralis**	x							1
*Hyla squirrella**	x	x			x		x	4
*Pseudacris nigrita**	x				x			2
*Pseudacris ocularis**	x				x			2
Leptodactylidae								
*Eleutherodactylus planirostris**[1]		x					x	2
Microhylidae								
*Gastrophryne carolinensis**	x	x			x	x		4
Ranidae								
Rana capito		x						1
*Rana grylio**			x	x	x			3
*Rana sphenocephala**	x		x	x	x			4
Total	26	17	26	21	30	7	13	

of 0.5 to 1.0 m, were perhaps a linear analog to the extensive marsh historically present on the ranch and the isolated wetlands presently found on the ranch. The presence of many species even in pasture was expected given the ubiquity of isolated wetlands of variable size, depth, and hydroperiod (Babbitt, 1996) and the presence of scattered live oaks and cabbage palms between hammocks.

Collectively, the ranch might be considered one extensive ecotone between freshwater wetlands and hammocks with a similar species list predicted to occur in those habitats. The 53 species at BIR comprised 87% of the number of species (N = 61) within the geographic ranges of BIR, ENP, and KOPSMS. The chicken turtle (*D. reticularia*), stinkpot turtle (*S. odoratus*), slender glass lizard (*O. attenuatus*), scarlet snake (*C. coccinea*), kingsnake (*L. getulus*), coral snake (*M. fulvius*), brown water snake (*N. taxispilota*), and Eastern spadefoot toad (*S. holbrooki*) were present in ENP and KOPSMS, within the geographic range of BIR, but not recorded during this study. For all but *S. holbrooki,* absence from the checklist was probably from lack of sufficient collecting effort. *Sternotherus odoratus* could be present on BIR, even if apparently rare as it is in surrounding areas (pers. obs.). Because of the ubiquity of feral hogs (*Sus scrofa*) and nine-banded armadillos (*Dasypus novemcinctus*), *C. coccinea* and *M. fulvius* are probably actually rare in the hammocks in which they would likely occur. The Harney Pond Canal is the likeliest place to find *N. taxispilota*.

I do not believe that *S. holbrooki* occurs on BIR. No *S. holbrooki* were heard or seen during torrential rainfall in March 1993 nor at any time during this study. Because this species burrows deep into the ground, it may be unable to tolerate the drainage patterns employed on the ranch whereby water levels are maintained at levels higher than normal during the dry season and lower than normal during the wet season.

Athough the indigenous species composition of BIR was as rich as predicted for natural habitats at two other locations in Florida, the suitability of BIR for each species and the effects of feral swine (*Sus scrofa*) and the nine-banded armadillo (*Dasypus novemcinctus*) are presently unknown and remain interesting and likely critical questions. In this regard, the substantial species list of BIR underscores the potential for stewardship by ranchlands of south-central Florida of a resilient herpetofauna that is experiencing a longterm perturbation of its habitat.

ACKNOWLEDGMENTS—Thanks are due to Dan and Anita Childs for their hospitality, camaraderie, and natural history observations. Discussions about the ranch herpetofauna with Kim Babbitt were, as always, insightful and fun. Erika Nowak contributed records and sightings on BIR. Betty Ferster reviewed an earlier version of this manuscript. Archbold Biological Station kindly provided opportunity for me to work on the ranch.

LITERATURE CITED

BABBITT, K.J. 1996. Graduate student. University of Florida, Gainesville, Florida. Pers. commun.

CHILDS, D.B. 1996. Ranch Manager. Buck Island Ranch, Lake Placid, Florida. Pers. commun.

DALRYMPLE, G.H. 1988. The herpetofauna of Long Pine Key, hydrology. Pp 72–86 *In* SZARO, R.C., K.E. SEVERSON, AND D.R. PATTON, (tech. coords.) Proc. symposium management of reptiles, amphibians, and small mammals in North America. U.S. For. Serv. Gen. Tech. Rep. RM-166.

DUELLMAN, W.E. AND A. SCHWARTZ. 1958. Amphibians and reptiles of southern Florida. Bull. Fla. State Mus., Biol. Sci. 3:181–324.

FRANZ, R.D. 1995. An introduction to the amphibians and reptiles of the Katharine Ordway Preserve-Swisher Memorial Sanctuary, Putnam County, Florida. Bull. Florida Mus. Nat. Hist. 38, PtI:1–10.

GODLEY, S.J., F.E. LOHRER, J.N. LAYNE, AND J. ROSSI. 1981. Distributional status of an introduced lizard in Florida: *Anolis sagrei*. Herpetol. Rev. 12(3):84–86.

LAYNE, J.N. 1993. History of an introduction of elk in Florida. Fla. Field Nat. 21(3):77–80.

LIPS, K.R. AND J.N. LAYNE. 1989. Vertebrates associated with gopher tortoises (*Gopherus polyphemus*) burrows in four habitats in south-central Florida. Fla. Scientist (Abstr.)

MESHAKA, W.E., JR. 1994a. Geographic distribution: *Ramphotyphlops braminus*. Herpetol. Rev. 25(1):34.

———. 1994b. Ecological correlates of successful colonization in the life history of the Cuban treefrog *Osteopilus septentrionalis* (Anura: Hylidae). Ph.D. dissert. Florida International University. Miami, Florida.

———. 1995. Reproductive cycle and colonization ability of the Mediterranean gecko (*Hemidactylus turcicus*) in south-central Florida. Fla. Scientist 58(1):10–15.

———. 1996a. Vagility and the Florida distribution of the Cuban treefrog (*Osteopilus septentrionalis*). Herpetol. Rev. 27(1):37–40.

———. 1996b. Diet and the colonization of buildings by the Cuban treefrog, *Osteopilus septentrionalis* (Anura: Hylidae). Caribbean Journal of Science 32(1–2):187–190.

———, B.P. BUTTERFIELD, AND J.B. HAUGE. 1994a. *Hemidactylus mabouia*: Geographic distribution. Herpetol. Rev. 25(4):165.

———, B.P. BUTTERFIELD, AND J.B. HAUGE. 1994b. *Hemidactylus mabouia* as an established member of the Florida herpetofauna. Herpetol. Rev. 25(2):80–81.

——— AND B.A. MOODY. 1996. The Old World tropical house gecko (*Hemidactylus mabouia*) on the Dry Tortugas. Fla. Scientist 59(2):115–117.

TEBEAU, C.W. 1968. Man In The Everglades: 2,000 Years of Human Use In The Everglades National Park. 2nd ed. Univ. Miami Press. Miami, Florida.

Florida Scient. 60(1): 1–7. 1997
Accepted: June 15, 1996

WATER QUALITY MEASURES ON FLORIDA DAIRIES: ISSUES OF REGULATION AND FARM SIZE[1]

P. F. Monaghan(1), M. E. Swisher(2) and H. H. Van Horn(3)

(1)Anthropology Department, (2)Department of Home Economics, (3)Dairy and Poultry Science
Department, University of Florida, Gainesville, FL 32611

Abstract: *The Florida dairy industry consists of 180,000 cows located on fewer than 300 farms. Most farms have 300–500 cows while most dairy cows in the state are concentrated on farms with over 1000 cows. These confined animal operations produce large amounts of waste in manure and each farm must have a means of storing and utilizing it safely. In 1993, the Institute of Food and Agricultural Sciences at the University of Florida conducted a statewide survey of 66 dairy farmers to determine how many were managing waste using best management practices. We found that most dairies in the state do not monitor the amount of waste that is generated or disposed of on the farm. However, depending on the size and location of the dairy, the majority of cows in the state are located on farms that utilize BMPs.*

Since 1987, Florida dairy farmers have faced a steady increase in regulations covering the disposal of manure and wastewater. The Department of Environmental Regulation (DER) had been conducting research on phosphorus loading in Lake Okeechobee for several years when, in 1986, nutrient overloading resulted in a 120-mile algae bloom. The governor ordered the DER to enact strict pollution measures, called "the Dairy Rule," to contain phosphorus on dairies in the lake's watershed. A buyout program was offered at the same time. Eighteen barns closed instead of investing in new wastewater systems. The remaining dairies spent an average of $1.2 million each to improve waste management (Boggess, 1993). The economic losses to Okeechobee County were estimated at $47.6 million in sales, 465 full-time equivalent jobs, and almost $9 million in earnings (Mulkey and Clouser, 1991).

In 1990, attention shifted to the Suwannee River basin because research demonstrated the potential for nitrate contamination in the shallow aquifer (Andrews, 1992). The Natural Resources Conservation Service and the Water Management District began implementing a plan of technical assistance and cost share to improve waste handling.

The DER, since renamed the Department of Environmental Protection (DEP), has now announced a statewide dairy rule. This rule mandates uniform regulations and wastewater requirements for all dairies, regardless of size. It will likely require a monitoring permit for all dairies. This would require drilling test wells and periodic monitoring of water quality. Farmers may have the option of installing liners in waste lagoons, which could exempt them from the monitoring permit requirement.

---

[1] Florida Journal Series No. R-04913.

This paper presents the results of a survey conducted in 1993 by the University of Florida Institute of Food and Agricultural Sciences (IFAS) of 66 dairy farmers. The objective was to document on-farm changes made over the last decade to improve waste management. IFAS asked farmers whether they used best management practices (BMPs) such as installing lined waste lagoons, developing farm nutrient budgets, and monitoring water quality and water use on the farm. Summarizing the results, we found that most dairies have not begun to adopt any of the technology recommended in the years since the Okeechobee dairy rule. This is especially true of the 45 percent of dairies in Florida that have fewer than 300 cows. Results of the study show that only 16% of dairies have lined their wastewater lagoons. Only about one-third of all dairy farmers, 31%, monitored water quality on their farms in 1993.

Many changes required for BMPs, such as building new barns to handle waste or constructing cement-lined lagoons, are expensive. Farmers have found that production per cow increases under some new systems, particularly those that offer more shade and better comfort for cows. However, most investments made to meet environmental regulations cannot be recovered. Drilling test wells to monitor water quality and hiring consultants to do the reporting, for example, does not increase production.

Despite the drawbacks, most dairies are gradually changing to meet higher water quality standards. Further, most *dairy cows,* in contrast to most *dairies,* are subject to BMPs because most cows in the state are concentrated on large farms that are more closely regulated. Florida dairy farmers in all size categories are experimenting with artificial wetlands, total pasture feeding, and improved herd management directed at controlling the flow of nutrients and wastes on the farm.

The most important factors that determine whether a farmer installs new waste management BMPs are the number of cows in the herd and the year the farm was established. Regulations play a role in determining the importance of these factors. For example, certain regulations would apply to the establishment of a new dairy which would not affect dairies already in existence. However, regional ecological issues, such as water quality in the Suwannee River basin, can increase regulatory pressures. The individual farmer must choose a system that fits his or her operation and the environment in which it is located.

When asked to rank the importance of different factors affecting both the profitability of their farms and the future of the Florida dairy industry, dairy farmers consider increased regulation and nuisance complaints to be as critical as the price of milk. However, changing technology and regulatory uncertainty have caused most dairy managers to take a "wait and see" attitude. This paper explores the experiences and options available to dairy farms varying in size and location within the different regions of Florida.

METHODS—The sample for the survey was taken from the producer lists maintained by the Florida Department of Agriculture and Consumer Services. The content of the survey instruments was based on interviews with IFAS researchers involved in nutrient and water management research. Recent extension recommendations were also reviewed and incorporated into the instrument. All producers were asked to participate in personal interviews lasting approximately 30 minutes and all contacted farmers responded to the survey. The survey included questions about farmer characterisitics, farm size and description, and waste management facilities. Farmers were also asked to report changes in their operations over the past decade and to provide their opinions about the future of dairying in the state of Florida. Interviews were conducted in Fall 1993 through Spring 1994.

RESULTS AND DISCUSSION—The Florida dairy industry consists of about 300 producers spread over 46 counties with milk sales of almost 400 million dollars in 1993 (Florida Agricultural Statistics Service, 1993). However, most of the milk produced comes from regional clusters of farms. Dairy herds in Okeechobee, Lafayette, Gilchrist, Hardee, Hillsborough, Highlands, and Clay counties produced more than half of this milk. One quarter of all milk in the state comes from a small number of farms in Okeechobee County. A regional group of approximately 80 small and mid-sized farms clustered in the Middle Suwannee region produce 19% of the total milk in the state. During the past ten years, suburban development has caused a steady decline in the total number of dairies clustered in the older dairy region of eastern Hillsborough County.

The average number of cows per farm is 580, however 15 percent of farms milk more than 1000 cows. Individual Florida dairy herds are large compared to the national average of 60 head per farm. The large Florida herds reflect a trend in the dairy industry toward large, labor and capital intensive farms. Dairies with these characteristics are now found throughout the Sunbelt in Texas, California, Arizona and New Mexico. Florida's current herd is concentrated on 30% fewer farms than a decade ago. Since the 1980s, nearly every existing farm expanded its herd size.

Still, Florida ranks 15th nationwide in total number of dairy cows with less than 180,000 cows. The total Florida herd is not large compared to states such as Wisconsin and California, which both have dairy herds of over a million cows. Further, the total Florida herd is down from a high of 190,000 in the early 1980s. Just as important, the industry has modernized and geared practices toward maximum milk production per feed unit. Production per cow is up 33 percent, and the 1993 herd of 180,000 produced more milk than did 190,000 cows in 1983 (Florida Agricultural Statistics Service, 1993).

Nonetheless, the heat and humidity in Florida from May to October keep the average production per cow low. Florida ranks 22nd nationwide in production per cow, and Florida's average of 14,371 pounds per cow is lower than the US average of 15,554. The stress of Florida's heat results in culling rates that average 30+ cows per hundred per year. It is more economically efficient for farmers to milk large herds, purchase all or most of the feed, and buy replacements rather than raise calves.

Dairy farms in Florida—Florida's environment not only shapes production practices, but also waste management strategies. Waste management on Florida dairies is an important issue because of the state's permeable soils and unique hydrological features. Waste disposal problems can occur when cows are confined to small pasture areas or when waste is flushed out of barns and stalls into holding ponds. A cow producing 100 pounds of milk per day also produces 195 pounds of manure and urine (Van Horn et al., 1991). A 100 cow herd will therefore produce about 4,747,500 pounds of raw manure in a year (Van Horn et al., 1991). This manure may contain as much as 22,000 pounds of nitrogen (N) and 4,500 pounds of phosphorus (P) (Van Horn et al., 1991). Surprisingly, the fertilizer produced by a 1000-cow herd is often not sufficient for production of adequate quantities of high quality forages and farmers may apply non-organic nutrients as well.

To manage dairy waste, barns are first flushed with water. The combination of solids and liquid is held in shallow ponds on the farm where the mixture separates and some liquids evaporate. Most farms spray liquid effluent or slurry on to fields to fertilize hay or pasture grasses. The greatest danger to water quality would be release of excess N and P from this concentrated waste in the lagoons or pastures into aquifer recharge groundwater, streams or lakes.

Both (N) and (P) are nutrients that come from the diet eaten by dairy cows. The crude protein in the diet of high producing cows is usually about 17.5 percent N, and P is an important mineral for animal health (Van Horn et al., 1991). In the soil, the excreted organic nitrogen in cow manure can be transformed to nitrate nitrogen, which percolates downward through the soil, eventually reaching groundwaters unless taken up by plants or reduced to N_2 gas by microbes. High levels of nitrate nitrogen in ground water can cause birth defects, cardiovascular problems, bluebaby syndrome and may increase the risk of stomach cancer and leukemia (Andrews, 1992). When N or P is a limiting nutrient in surface waters, as they are in the Suwannee river, excess levels of these nutrients leaching from dairies can cause waterway eutrophication.

Phosphorus is more difficult to recycle as fertilizer than N because pasture and forage crops utilize smaller amounts of P than N. Therefore, in regions where P containment on a dairy is a problem, such as the Lake Okeechobee basin, effluent sprayfields must be larger. Some farms also reduce the amount of P in the diet fed to their cows. Local geological patterns may determine whether dairies must meet the stricter P regulations. Soils with a clay layer above the water table for example, are less vulnerable to

P leaching, and therefore sprayfield size and lagoon liner requirements may vary.

Waste management technologies—Waste management on dairies consists of three steps. First, the feces and urine are collected, then contained on an area of the farm, and finally treated and utilized on fields or removed from the farm altogether. The survey showed that Florida dairy farmers perform these tasks using a variety of methods. Feeding barns and milking parlors are often water flushed with the liquid stored in shallow lagoons, where it settles and evaporates. On some farms, manure is scraped without additional water and then passed through a separator or piled for composting. Eventually any remaining waste is sprayed or distributed on fields, used as bedding for stalls or is transported off the farm for use as fertilizer. Utilizing dairy waste as fertilizer is one best management practice that farmers can use to safely recycle nutrients. Other BMPs include the use of a farm "nutrient budget", lining lagoons with plastic or concrete to prevent leakage, and regular on-farm water quality monitoring programs. Florida's high rainfall and humidity make it difficult to keep manure dry. Only a small percentage of farmers (17%) scrape manure solids from holding areas. Over 90% of farmers interviewed use water to flush cattle holding areas and then store the liquid mixture in an aneorobic lagoon. These basins must be cleaned periodically by removing the accumulated sludge.

The waste contained in a dairy lagoon has high levels of ammonium nitrogen, organic nitrogen, fecal coliform, and streptococcal bacteria (Andrews, 1992). Depending on the hydrogeologic characteristics, there is a potential for lagoons to leach nutrients into shallow groundwater, to overflow, or to leak when they are being cleaned out. One way to insure that this does not occur is to install new lagoons with linings made of concrete, plastic, or clay. Only 16% of dairy waste storage lagoons in the state are lined. Many of these are on dairies of over 1000 cows although most large dairies do not have lined waste lagoons. A few smaller farms (350 cows or less) have invested in linings for their waste lagoons. Most lined lagoons, regardless of herd size, have been installed since 1989.

The volume of manure and water on dairies with 300 or more cows would quickly overload most lagoons if farmers did not spray some of the water on their fields. Our survey found that 57% of Florida dairies recycle at least part of their manure nutrients by spraying effluent onto fields through a center pivot system. The usual crop is pasture grass, but silage, vegetable crops, and citrus are also irrigated with dairy effluent. Other waste handling systems, including mechanical separation or composting, are less common, with 17% of farmers applying manure onto fields using tractor drawn spreaders. Most of the farmers that compost and spread solids also spray lagoon effluent. A few farms in all size categories pile and compost manure and then market or give it away as fertilizer. Some farmers use compost for bedding their barns. There is also some potential for nutrient leaching from compost piles.

Florida dairy farms of all sizes reported that the total acreage sprayed has increased since 1982. Among large farms, the increase was over 100%, while smaller farms increased their acreage by about 50%. Most irrigation systems were purchased in the past decade as herd sizes increased.

Irrigation of dairy waste has limitations. The farm must have adequate land and grow crops capable of absorbing the nutrients produced by the herd. Overfertilizing may cause phosphorus loading of the soils, increasing the risk of contaminating surface and groundwaters. Groundwater beneath sprayfields in north Florida has shown elevated levels of N and P concentrations (Andrews, 1992). Another limitation to spraying large fields, particularly in the humid summer months is that it contributes to odor and fly problems, often causing complaints from downwind neighbors.

An estimated 25% of Florida dairy farms reported that they do not recycle waste in any way. They usually let liquids evaporate from lagoons (which should be dredged periodically). These farms are generally smaller (fewer than 300 cows) and do not confine their cows for much of the day. Dairy manure collects in feeding barns and stalls, with smaller amounts collected in milking parlors, loafing areas, walkways and intensively grazed pastures. Most of these farms have older systems and unlined lagoons. Small farms with considerable amounts of unused dairy waste will probably have to change their manure management practices in the future as new regulations come into play. Similar traditional systems would not be approved for new dairies by state environmental regulators.

The survey also asked farmers about several recommended best management practices for monitoring dairy waste and farm water quality. A nutrient budget, for example, is one step in monitoring nutrient flows (primarily nitrogen and phosphorus). The objective is to create a system in which all nutrients in feed either leave the farm as milk or are recycled through a crop, thereby preventing nutrient loss to surface and subsurface waters. In a nutrient budget, the amount of nutrients that cows consume in the form of feed are calculated. The total N fed to cows, for example, can be calculated based on crude protein content of feeds. The nutrients in the milk that leaves the farm are also determined. The remaining nutrients must be recycled through crops or removed from the farm. The capacity of a particular crop to use the available nutrients has to be calculated to avoid potential leaching of excess nutrients from the soil.

The survey found that only 19% of all farms had nutrient budgets. Many are found in the Lake Okeechobee drainage basin, where a nutrient budget and strict testing of nutrients in feed, effluent and harvested crops are required by state regulators. On the other hand, over half of the *cows* in the survey were on farms using nutrient budgets. Most of the dairies that use nutient budgets do not follow the rigorous testing required in the Lake Okeechobee region. Outside of the Okeechobee region, 13% of farmers use nutrient budgets, but they do not analyze the nutrient content of manure or crops. The newer and larger farms (1000 or more cows) have taken the lead in adopting this practice, with the result that many of the cows in the state are on farms which measure nutrient flow.

The majority of dairy farms in the state, including the large and technologically modern ones, do not calculate the amount of nutrients on their farms nor monitor their disposal. This means that while most farms spray liquid manure on their fields, without a nutrient budget and a regular testing program, there is no way to calculate their recycling effectiveness.

The survey also questioned farmers on whether they had installed groundwater testing wells on their farms or if they tested surface waters such as canals and streams for nutrient loading. Farmers usually have to hire a consultant to drill the wells, take periodic samples and test them for the presence of nitrates or bacteria. Drilling wells can be an expensive BMP. We found that 31% of farmers do test groundwater and/or surface water. Of these, half were farms located in the heavily regulated regions of the Suwannee River or Lake Okeechobee drainage basins. Most of the farms that test for water quality report their findings to regulators, or the testing program is administered by regulators. The dairies outside these two regions that test for water quality are mostly the largest farms of 1000 or more cows. As of 1993, the majority of small and mid-sized farms in the state did not test for water quality.

CONCLUSIONS—Dairy size is an important predictor of BMP use, but it is just one factor that shapes the adoption of environmentally sound BMPs. The year in which the farm was established, the regional location, the different combinations of management and technology styles adopted by owners and the way that environmental regulations are implemented all effect whether BMPs will be found on a particular farm. Farms established after the regulatory period of the late 1980s often submitted their waste management plans for approval by state regulators and assisting agenices such as the Natural Resources Conservation Service and water management districts. Farms located near expanding urban areas or in environmentally sensitive regions found themselves in conflict with citizens groups and local governments.

Since a definitive statewide rule on dairy waste standards has yet to be established, most farms are taking a "wait and see" attitude. Some are encouraged to try new waste management technologies, others are offered cost-share benefits from the state and most feel that taking action now does not guarantee that they will be exempt from scrutiny and later mandates to purchase waste management technologies. There are a growing number of dairy farms, both large and small that are attempting to avoid most of the waste management controversy by radically changing their operations to a pasture-based system with minimal waste problems. Finally, the current competitive milk markets will likely force many farms to get out of dairying before regulations force manure management changes.

Large farms have recently come to dominate Florida dairying, and more and more of them will comply with stricter regulations on handling their waste. It is the mid-size and smaller dairies, the majority of all farms in the state, that will be affected most dramatically by the increasing pressure to adopt BMPs. The managers of these farms will have to weigh environmental and market factors along with the pressures to expand and adopt new production technologies when they consider when and how to adopt waste management systems. This can be seen in the decision on whether to change to a pasture-based system or purchase the infrastructure needed for total herd confinement. Each choice has different costs and drawbacks, and each has different waste management options. The most important independent variable is how regulators will mandate and implement coming changes in waste management.

LITERATURE CITED

ANDREWS, W. J. 1992. Reconnaissance of Water Quality at Nine Dairy Farms in North Florida, 1990–91. U.S. Geological Survey Water Resources Investigations Report No. 92-4058. Prepared in cooperation with the Florida Department of Environmental Regulation.

BOGGESS, W. G. 1993. A case study of nutrient management for Florida dairies. Paper presented at the SRIEG-10 Meeting, Raleigh, NC, Oct. 22, 1993.

FLORIDA AGRICULTURAL STATISTICS SERVICE. 1993. Florida Dairy Summary. Florida Agricultural Statistics Service. Orlando, FL.

MULKEY, D. AND R. L. CLOUSER. 1991. The Economic Impact of the Dairy Industry in Okeechobee County, Florida. Staff Paper No. 91-40. Food and Resource Economics Department, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL, 36 pp.

VAN HORN, H. H., R. A. NORDSTEDT, A. V. BOTTCHER, E. A. HANLON, D. A. GRAETZ, AND C. F. CHAMBLISS. 1991. Dairy Manure Management: Strategies for Recycling Nutrients to Recover Fertilizer Value and Avoid Environmental Pollution. Circular No. 1016. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL, 16 pp.

Florida Scient. 60(1): 8–15. 1997
Accepted: June 25, 1996

RESPONSES OF TWO CLOSELY-RELATED RAIL SPECIES, *RALLUS LONGIROSTRIS* AND *RALLUS ELEGANS,* TO CONSPECIFIC AND HETEROSPECIFIC CALLS

ALI M. RABATSKY[1]

Department of Biology, Stetson University, DeLand, Florida 32720

ABSTRACT: *Recently, the classification of the clapper and king rail has been under debate. Because ornithologists may consider song when determining classification, I used playback recordings to compare the number of calls made by each rail to conspecific and heterospecific calls. Clapper and king rail calls were played in three saltwater marshes in east-central Florida during the spring breeding season. Both rails responded to both bird calls with no significant difference in frequency. These data support the classification of both rails as one species.*

THE classification of *Rallus longirostris* and *Rallus elegans* as distinct species has recently been under debate (Meanley, 1992). The clapper rail, *R. longirostris* is a secretive bird that inhabits saltwater marshes (Bull and Farrand, 1977). The king rail, *R. elegans,* is similar to the clapper rail except that it inhabits freshwater and brackish marshes (Bull and Farrand, 1977). Because these rails differ in various traits such as color, size, habitat preference and behavior, they have been classified as two separate species. However, in winter and spring, king rails migrate to the saltwater marshes and occasionally breed with the clapper rails (Meanley, 1992). If these matings produce successful hybrid offspring, then according to the biological species concept, the two rails should be considered one species (Primack, 1993). However, reproduction is infrequent and often difficult to observe.

Ornithologists may use song as a factor in determining classification (Payne, 1986). Bird song has many functions. A male may sing to gain and defend a territory (Pettinghill, 1970; Catchpole, 1989) against both conspecifics and heterospecifics (Payne, 1986). Birds may also use song to communicate the species and sex of the singer (Pettinghill, 1970). In this context, song acts as an isolation mechanism that ensures that only birds of the same species will mate (Pettinghill, 1970). If song is a dominant isolation mechanism in birds, each species of bird should have its own song. This idea has been coined by Marshall (1978) as the "one song, one species" concept.

The clapper and king rail each have one call that is distinct and a second call that is shared (Holliman, 1978). A third call, the "kek-burr" song is used only in the breeding season by the female king rail (Manolis, 1981; Zembal and Massey, 1985). If one species of rail responded to another species of rail in the defense of a territory, it is not evident that the species are distinct. Again, this is because birds may defend territory against both conspecifics and heterospecifics (Payne, 1986). However, if the king rail responds with its "kek-burr" call to a clapper rail call or if a clapper rail calls in response to the "kek-burr" call during the breeding season, then according to Marshall's "one species, one song" concept, the two rails are the same species. In the first part of this study, I attempted to gain a better understanding of the relationship between these rails by comparing the number of calls made by each species to conspecific and heterospecific calls during the breeding season. Furthermore, to ensure that my study population only used the "kek-burr" call in the breeding season, I measured the frequency of this call in the breeding and non-breeding season.

---

[1] Current address: 940-B Grove Hamlet Way, DeLand, FL 32720

METHODS—to compare the number of calls made by each species to conspecific and heterospecific calls, I played tape recordings of clapper rail and king rail calls in marsh habitat in east-central Florida during the spring breeding season of 1995. Study sites included three saltwater marshes along highway US 1 in Volusia County, Florida. Three different vocalizations recorded by Walton and Lawson (1994) were used. A musical recording and a soundless recording were also played to serve as controls. All recordings were played by a portable tape player and were of approximately equal loudness. All four recordings were played at each site. When a trial was run, I positioned myself and the tape player at the marsh's edge. Recordings lasted one minute and were separated by two minutes to allow the rails time to respond. The number of calls and the species of the responder were noted for each recording. Multiple calls from the same bird were counted. Treatments were conducted two hours before dark and the order in which they were conducted was randomized. I repeated this procedure after the breeding season of 1995 to measure the frequency of the king rail's "kek-burr" call.

RESULTS—All data were analyzed using one-tailed t-tests. Both clapper ($t=4.87$, $p<0.05$) and king ($t=2.8$, $p<0.05$) rails responded significantly more often to bird sounds than to the controls. Clapper rails responded significantly more often than king rails to all stimuli ($t=8.3$, $p<0.05$). Clapper ($t=.24$, $p>0.05$) and king rails ($t=1.7$, $p>0.05$) did not respond significantly more often to their own recordings than they did to each others (Figure 1.). The "kek-burr" call of the king rail was heard significantly more often in the breeding season than in the non-breeding season ($t=2.66$, $p<0.05$).

DISCUSSION—Clapper rails responded in a greater number of trials than did the king rail in both the breeding and non-breeding season. This could be for at least two reasons. First, there could be a greater number of clapper rails present. Since this study was conducted in saltwater marshes, this hypothesis seems likely. Secondly, clapper rails may be more vocal than king rails.

The "kek-burr" call of the king rail was heard more often in the breeding season than in the non-breeding season and supports the observations

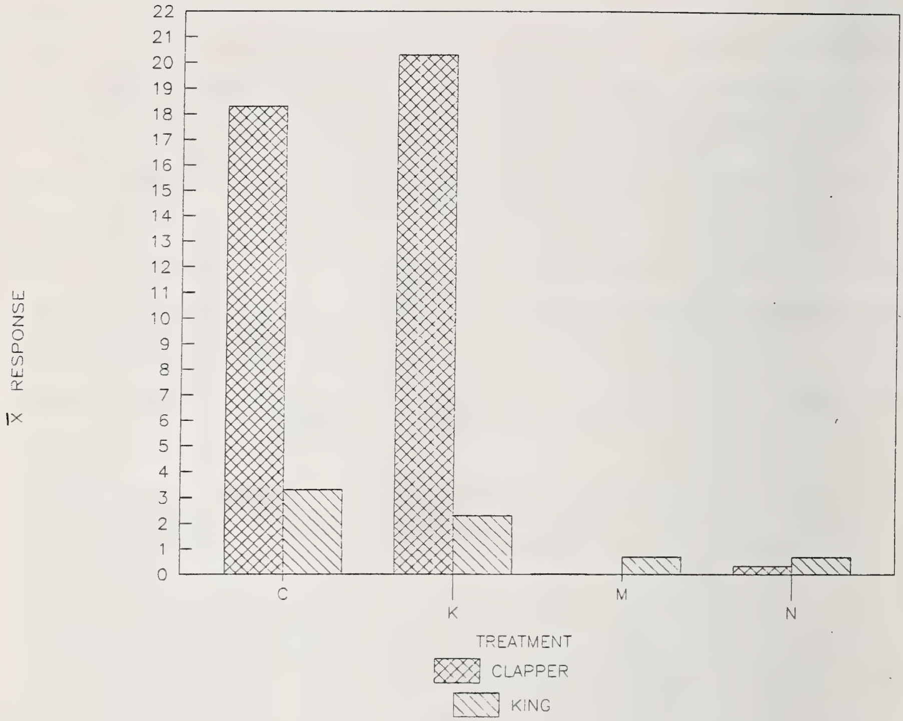


FIG. 1. Average number of responses made by each species to each of four trials (C=clapper rail call, K=king rail call, M=musical recording, N=soundless recording) at each study site.

of Manolis (1981) and Zembal and Massey (1985). These observations are consistent with the hypothesis that the functions of the "kek-burr" call are strictly related to breeding activities (Zembal and Massey, 1985).

During the breeding season, I believe that these rails were responding both to defend a territory and to attract a mate. When defending a territory, birds usually show aggressive behavior. I observed this on several occasions. I was approached by the rails several times and in one instance, a king rail spread its wings and ran towards me. Also, when two or more rails were in close proximity, they would usually chase each other. However, I also heard the "kek-burr" call of the female king rail in 80% of the trials. Because my study population uses the "kek-burr" call only in the breeding season and both rails responded to both conspecific and heterospecific calls with no significant difference in frequency, then these rails may be considered as one species according to Marshall's concept.

Other evidence supporting the classification of these rails as one species should be considered. Avise and Zink (1988), found Rallus mtDNA to show intraspecific polymorphism. Variation among individuals was also present, with some rails carrying up to 75% of the possible genomes. Both the clapper and king rail also had a high percentage of the same two genomes. It may be that these rails are one species with a high proportion of genetic variability (Avise and Zink, 1988).

The clapper and king rail may also be classified as one species based on the definition of a biological species. There may be two different forms of this rail as a result of resource partitioning. A part of the population may move inland in the fall and winter to reduce interspecific competition for food. When it is time to mate in the spring, the population may rejoin. By being geographically isolated for a part of the year, these rails may experience different selection pressures. For example, habitat differences may explain why the rails evolved slight differences in color.

If we consider these rails as one species, then why do we hear variation in song? Intraspecific variation in song is common among allopatric populations of birds (Payne, 1986). The variation we hear in rails may let them know who moves inland in the summer and who stays near the coast. For example, a female clapper rail may not choose to mate with a male that will leave the nest in the summer to return inland.

The classification of an organism is important to understanding its ecology and its relationships to other species. Several morphological and behavioral components need to be considered when classifying an organism. Because of intraspecific variation in song, variation in function (Payne, 1986) and variation in response, the component of song should not be considered alone when classifying birds. My data are consistent with the findings of Avise and Zink (1988) and support the classification of the clapper and king rail as one species. The definition of the biological species is critical and further studies measuring the survivorship and fecundity of hybrid rails may lead to a better understanding of the classification of the these rails.

ACKNOWLEDGMENTS—Thanks to A. Evans, T. Farrell, and P. May for assistance in various phases of this study.

LITERATURE CITED

AVISE, J. C. AND R. M. ZINK. 1988. Molecular genetic divergence between avian sibling species: king and clapper rails, long-billed and short-billed dowitchers, boat-tail and great-tailed grackles, and tufted and black-crested titmice. The Auk. 105:516–528.

BULL, J. AND J. FARRAND, JR. 1977. The Audubon Society Field Guide to North American Birds. Eastern Region. A.A.Knopf, Inc., New York, NY. 784pp.

CATCHPOLE, C. K. 1989. Responses of male sedge warblers to playback of different repertoire. Anim. Behav. 37:1046–1048.

HOLLIMAN, D. C. 1978. Clapper rail studies in Alabama. Northeast Gulf Sci. (2)1:24–34.

MARSHALL, J. T. 1978. Systematics of smaller Asian night birds based on voice. Ornithol. Monogr. 25.

MANOLIS, T. 1981. The "kicker" song-new synthesis of an old mystery. Am. Birds 35:261–263.

MEANLEY, B. 1992. King Rail. The birds of North America. 3:1–12.

PAYNE, R. B. 1986. Bird songs and avian systematics. Current Ornithology 3:87–126.

PETTINGHILL, O. S. 1970. Ornithology in the lab and field. 4th ed. Burgess Pub. Co., Minneapolis, MN. 524pp.

PRIMACK, R. B. 1993. Essentials of Conservation Biology. Sinauer Associates, Inc., Sunderland, MS. 564pp.

WALTON, R. K. AND R. W. LAWSON. 1994. More Birding by Ear. Peterson's Field Guide Series, Eastern and Central North America. 1994. Houghton Mifflin Co., New York, NY.

ZEMBAL, R. AND B. W. MASSEY. 1985. Function of a rail "mystery" call. U.S. Fish and Wildlife Ser. Laguna Niguel, CA.

Florida Scient. 60(1): 16–20. 1997
Accepted: July 9, 1996.

STUDIES ON FLORIDA CHRYSOPHYCEAE (PARAPHYSOMONADACEAE) AND SYNUROPHYCEAE (MALLOMONADACEAE). V. THE FLORA OF NORTH-CENTRAL FLORIDA

DANIEL E. WUJEK(1) AND PETER A. SIVER(2)

(1)Department of Biology, Central Michigan University, Mt. Pleasant, MI 48859
(2)Department of Botany, Connecticut College, New London, CT 06320

ABSTRACT: *A total of 32 scaled chrysophytes (20* Mallomonas *spp, 7* Synura *spp, 2* Spiniferomonas *spp and 2* Paraphysomonas *spp and 1* Chrysosphaerella *sp) in 19 waterbodies from six north-central Florida counties were recorded using TEM. The number of taxa per location varied from 0 to 10. Seven taxa,* Mallomonas corcontica, M. dickii, M. elongata, M. leboimei, M. schwemmlei, Synura mammillosa *and* Chrysosphaerella coronacircumspina, *are new records from Florida.*

THE first EM record of a scaled chrysophyte in a Florida lake was by Wujek (1983) from central Florida. Later studies were expanded to include other parts of Florida (central Florida-Wujek, 1984; Wujek and Gardiner, 1985; Wee and Wujek, 1986; southern Florida-Wujek and Bland, 1988, 1991). Additional studies included the observations of Siver (south-central Florida-1994; Siver and Wujek, 1993).

The north-central region of Florida has yet to be investigated. The present paper reports and discusses scaled chrysophytes from 19 lakes, ponds, and rivers from six counties in this region.

MATERIALS AND METHODS—Plankton net (10 μm mesh) collections were made over the period extending from 2–5 March 1995 (Table 1). Preparation and observations were as previously described (Wujek, 1984; Wujek and Bland, 1988, 1991).

RESULTS AND DISCUSSION—A total of 32 silica-scaled chrysophyte taxa from the genera *Mallomonas* (20 taxa), *Synura* (7 taxa), *Spiniferomonas* (3 taxa) and *Paraphysomonas* (2 taxa) were observed from the 19 samples (Table 2). Because the collections were all made during the winter period we suspect that many additional species typically found in Florida localities also exist in this region. Seven of the species are new to Florida (*Mallomonas corcontica, M. dickii, M. elongata, M. leboimei, M. schwemmlei, Synura mammillosa* and *Chrysosphaerella coronacircumspina*: Figs. 1–7).

The number of scale-bearing chrysophyte taxa observed per sample varied from 0 to 10. Species richness tended to increase with increasing lake size. The most frequent *Mallomonas* species in the study were *M. akrokomos*

TABLE 1. Florida sampling sites March, 1995.

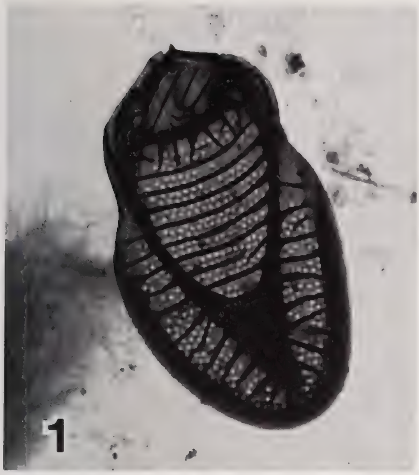
Sample #	Location		County	pH	Temp (°C)
2 March					
1	Ocean Pond	T3S R19E Sec20	Baker	6.0	18
2	Palestine Lake	T14S R19E Sec27	Union	6.0	19
3	Lake Butler	T5S R20E Sec30	Union	6.0	18.5
4	Suwannee River	T12S R15E Sec12	Hamilton	6.0	17
5	Farmer's Market Pond	T12S R15E Sec11	Hamilton	6.1	20
6	DeSoto Lake	T3S R17E Sec32	Columbia	6.1	19
7	Alligator Lake	T4S R17E Sec4	Columbia	6.1	19
3 March					
8	Lake Montgomery	T4S R17E Sec4	Columbia	6.0	18
9	Santa Fe River	T7S R17E Sec28	Columbia	6.0	19
10	Marmaduke Pond	T9S R19E Sec22	Alachua	6.0	10
11	Tenley Pond	T9S R19E Sec15	Alachua	6.1	22
12	Lake Alice	T10S R19E Sec12	Alachua	6.3	21
13	Bivens Lake	T10S R20E Sec16	Alachua	6.3	22
14	Lake Wauberg	T11S R20E Sec16	Alachua	6.1	21
5 March					
15	Spring Lake	T16S R23E Sec9	Marion	6.3	18
16	Lake Joy	T16S R23E Sec10	Marion	6.4	22
17	Lake Weir	T17S R24E Sec5	Marion	6.0	22
18	Lake Coronado Pines/ Blue Sink	T17S R26E Sec20	Marion	6.0	22
19	Nicotoon Lake	T17S R26E Sec21	Marion	6.1	26

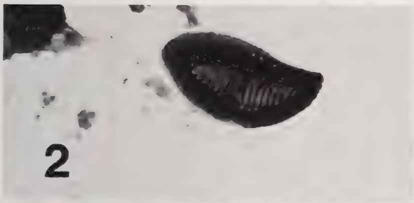
(37%), *M. cyathellata* var. *cyathellata* (26%) *M. transsylvanica* (21%) and *M. caudata* (21%). Common species from other genera were *Synura petersenii* (26%), *Paraphysomonas vestita* (26%), and *Spiniferomonas trioralis* (16%). Rare species included *Mallomonas corcontica, M. leboimei, M. mangofera* f. *foveata, M. ouradion, M. paludosa, M. papillosa* var. *papillosa, M. pillula* f. *pillula, M. schwemmlei, Synura mammillosa, S. uvella, Paraphysomonas imperforata, Spiniferomonas alata* and *Chrysosphaerella coronacircumspina.* Surprisingly, the Suwannee River sample had the highest number of taxa. Based on over 100 published floras of scaled chrysophytes representing areas around the world, none report riverine habitats as being very diverse. It is possible that some of the species found in the Suwannee River collection were actually contributed from upstream seepages, such as the Suwanoochee Creek and Okefenokee Swamp. Indeed, our other river

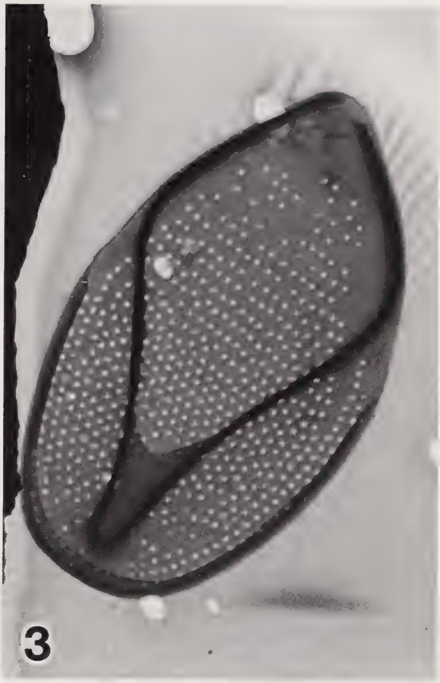
---

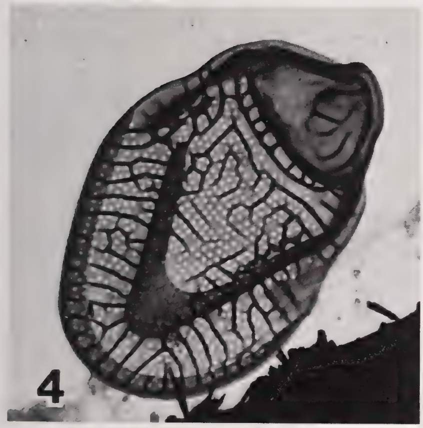
→

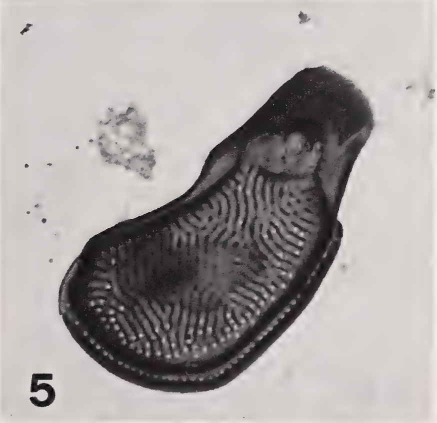
FIG. 1. *Mallomonas corcontica,* a dome-bearing scale. Fig. 2. *M. dickii,* a loose scale. Fig. 3. *M. elongata,* body scale. Fig. 4. *M. leboimei,* a single domed body scale. Fig. 5. *M. schwemmlei,* an asymmetrical apical scale. Fig. 6. *Synura mammillosa,* a spined scale. Fig. 7 *Chrysosphaerella coronacircumspina,* scales from body and base of spine. Scale bar = 1 μm.

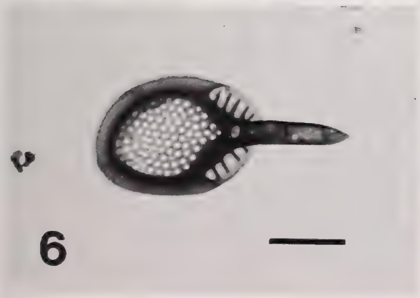

1


2


3


4


5


6

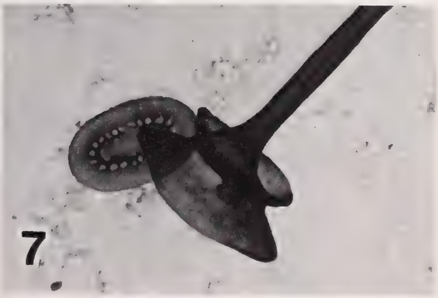

7

TABLE 2. The distribution of scaled chrysophytes from 19 waterbodies situated in north-central Florida during March, 1995. See TABLE 1 for localities. Taxa indicated with an asterisk were represented by scales only, not whole cells.

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
No. taxa/collection	7	9	6	10	3	8	5	5	0	5	1	3	2	1	0	3	3	2	2
Mallomonas akrokomos Ruttner*	+	+	+	+		+	+									+			
M. caudata Ivanov em. Krieger							+									+	+		+
M. corcontica (Kalina) Péterfi & Momeu*				+															
M. crassisquama (Asmund) Fott	+					+										+			
M. cyathellata v. Wujek & Asmund *cyathellata*					+	+		+		+		+							
M. dickii Nicholls*		+	+																
M. elongata Reverdin*						+	+												
M. hamata Asmund*	+	+																	
M. leboimei Bourrelly*		+																	
M. mangofera f. *foveata* Dürrschmidt*								+											
M. multiunca Asmund*	+							+											
M. ouradion Harris & Bradley*				+															
M. paludosa Fott*					+														
M. papillosa Harris & Bradley v. *papillosa**								+											
M. pillula Harris f. *pillula**				+															
M. portae-ferreae Péterfi & Asmund		+			+					+									
M. schwemmlei Glenk em. Glenk & Fott*						+													
M. striata v. *serrata* Harris & Bradley*				+						+									

TABLE 2. Continued.

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
M. tonsurata Teiling em. Krieger											+								
M. transsylvanica Péterfi & Momeu*	+	+		+								+						+	
Synura australiensis Playfair	+	+	+																
S. curtispina (Petersen & Hansen) Asmund*	+									+									
S. echinulata Korshikov*			+	+						+									
S. mammillosa Takahashi*				+															
S. petersenii Korshikov f. *petersenii*		+		+			+	+									+		
S. sphagnicola (Korsh.) Korshikov*			+	+															
S. uvella Ehrenberg em. Korshikov*							+												
Paraphysomonas imperforata Lucas*						+							+						
P. vestita (Stokes) de Saedeleer		+	+			+							+	+					
Chrysosphaerella coronacircumspina Wujek & Kristiansen*								+											
*Spiniferomonas alata** Takahashi																			+
S. trioralis Takahashi						+											+	+	

sample, from the Santa Fe River, did not contain any scaled chrysophytes. Further work would be needed in order to determine if the populations were actually growing in the riverine habitats.

The range in temperature (17 to 26 °C) and the time of year may indicate that the collections contained elements of the winter and summer floras. Species that were common in this study, such as *Mallomonas akrokomos* and *M. transsylvanica,* have often been observed under the ice in more northern regions (Siver 1991; Cronberg and Kristiansen, 1980). On the other hand, taxa such as *M. dickii,* and *Synura sphagnicola,* are more commonly observed during the summer (Siver, 1991), supporting the idea that our collections do contain elements of both the summer and winter floras.

The pH of the waterbodies ranged from 6.0 to 6.4, and were mostly stained with dissolved humic substances. Many of the species observed in these localities, including *Mallomonas corcontica, M. dickii, M. paludosa, M. schwemmlei, M. transsylvanica, Synura echinulata, S. mammillosa, S. sphagnicola* and *Spiniferomonas alata,* have been previously reported as common in acidic habitats (Siver, 1988, 1989, 1991). Our observations clearly support these earlier findings.

In conclusion, as has been demonstrated in other regions of Florida, the north-central area contains a diverse flora of scaled chrysophytes. We believe further observations will yield additional records. Including this paper, the scaled chrysophytes found in Florida now comprises 67 taxa.

ACKNOWLEDGMENTS—D.E.W. would like to thank Paul R. Elsner for preparing the carbon-coated grids and Central Michigan University's Graphics Production for their assistance in the preparation of the photographic plates.

LITERATURE CITED

CRONBERG, G. AND J. KRISTIANSEN. 1980. Synuraceae and other Chrysophyceae from central Småland, Sweden. Bot. Notiser 133:595–618.

SIVER, P.A. 1988. Distribution of scaled chrysophytes in 17 Adirondack (New York) lakes with special reference to pH. Can. J. Bot. 66:1391–1403.

———. 1989. The distribution of scaled chrysophytes along a pH gradient. Can. J. Bot. 67: 2120–2130.

———. 1991. The Biology of *Mallomonas*: Morphology, Taxonomy, and Ecology. Kluuwer Academic Publishers, Norwell, MA, 230 pp.

———. 1994. *Mallomonas wujekii* (Synurophyceae), a new species from Florida, U.S.A. Nord. J. Bot. 14(4):467–471.

——— AND D.E. WUJEK. 1993. Scaled Chrysophyceae and Synurophyceae from Florida: IV. The flora of Lake Myakka and Lake Tarpon. Florida Scient. 56(2):109–117.

WEE, J.L. AND D.E. WUJEK. 1986. Two new species of Paraphysomonadaceae (Chrysophyceae). Nova Hed. 43(1–2):81–86.

WUJEK, D.E. 1983. A new freshwater species of *Paraphysomonas* (Chrysophyceae). Trans. Amer. Micros. Soc. 102(2):165–168.

———. 1984. Chrysophyceae (Mallomonadaceae) from Florida. Florida Scient. 47(3):161–170.

——— AND R.G. BLAND. 1988. *Spiniferomonas* and *Mallomonas*: descriptions of two new taxa of Chrysophyceae. Trans. Amer. Micros. Soc. 107(3):301–304.

——— and R. G. Bland. 1991. Chrysophyceae (Mallomonadaceae and Paraphysomonadaceae) from Florida. III. Additions to the flora. Florida Scient. 54(1):42–48.

——— and W.E. Gardiner. 1985. Chrysophyceae (Mallomonadaceae) from Florida. II. New species of *Paraphysomonas* and the pyrmnesiophyte *Chrysochromulina*. Florida Scient. 48(1):59–63.

Florida Scient. 60(1): 21–27. 1997
Accepted: July 9, 1996.

ACKNOWLEDGMENT OF REVIEWERS

It is a pleasure to acknowledge the cooperation, dedication, and valuable service performed by the following persons, who generously donated their time and expertise in reviewing manuscripts for volume 59. Some kindly reviewed more than one manuscript.

Jesse S. Binford
Bruce C. Cowell
Clinton J. Dawes
Patricia M. Dooris
Robert W. Flynn
Cherie Geiger
Walter Jaap
Ken Langeland
John M. Lawrence
James N. Layne
Carl Luer
Fred Morris
R. J. Murphy
Larry Newton
Carl D. Riggs
Frank J. Schwartz
F. F. Snelson
Mark Stewart
William H. Taft
Walter Kingsley Taylor
Richard P. Wunderlin

Biological Sciences

WATER-SOLUBLE MUTAGEN PRODUCTION DURING THE BIOREMEDIATION OF OIL-CONTAMINATED SOIL

WILLIAM C. BLODGETT, JR.

Wellington High School, 2101 Greenview Shores Boulevard,
West Palm Beach, Florida 33414

ABSTRACT: *The illegal dumping of used motor oil is an environmental hazard with global ramifications. Bioremediation is a process that utilizes microorganisms to convert contaminants to less harmful materials. This study sought to determine if a water-soluble mutagen was a by-product of this process. The first of six tests simulated a dumpsite of used motor oil. A mixture of hydrocarbon-degrading bacteria biodegraded the oil for twelve weeks. The amount of oil that had been biodegraded was calculated through a Total Recoverable Petroleum Hydrocarbon (TRPH) test. A Polycyclic Aromatic Hydrocarbon (PAH) test measured decreases in the amounts of twenty-six hydrocarbons. In most samples, the level of naphthalene dropped within the first two weeks, and was almost completely gone by the third week. An Ames (Salmonella mutagenicity test) assay detected frameshift mutagens during the first two weeks. These results coincided with the decline in naphthalene levels. Thus, the data suggest that the biodegradation of naphthalene produced a putative mutagen.*

NORTH Americans generate about 1.4 billion gallons of used oil every year—sixty-three percent from vehicles and the rest from industrial sources. Fifty-five percent of the used oil is recycled (Hong, 1991). Much of the rest, laden with aromatic and halogenated hydrocarbon solvents, is discarded and left to seep into groundwater or otherwise contaminate the earth.

The accepted premise of bioremediation involves the use of microorganisms to convert contaminants to less harmful chemicals, such as carbon dioxide and water (Norris et al., 1993). This study sought to determine whether or not the microorganisms involved in this process also produced a water-soluble mutagenic by-product.

METHODS AND MATERIALS—*Biodegradation of oil*—Biodegradation experiments with used motor oil were performed in eight 30.9 L (60 cm × 45 cm × 15 cm) plastic containers. 11.25 kg of soil and 800 ml of used motor oil were added to each container. Four different variables were created: A, B, C, and D, as described in Table 1. The soil of variable D was sterilized in an oven at 232° C for two hours (Claus, 1990). The soil of variables B and C was inoculated with 125 ml of a mixture of known hydrocarbon-degrading bacteria. The bacteria used, *Nocardia parraffinae, Arthrobacter parraffineus,* and two *Arthrobacter* species, were obtained from Custom Biologicals, Inc. (Boca Raton, Florida).

The bacteria were incubated with the oil for twelve weeks at 25° C and pH of 7.0. Throughout that time, the levels of moisture and ammonia-nitrogen in the soil were monitored. A 20% moisture rate was maintained as closely as possible (Colwell and Leahy,1990). To maintain the level of ammonia-nitrogen, a mixture of urea, ammonium and potassium phosphates, and potassium nitrate was added weekly (Riser-Roberts, 1992). Supplementary mineral nutrients were

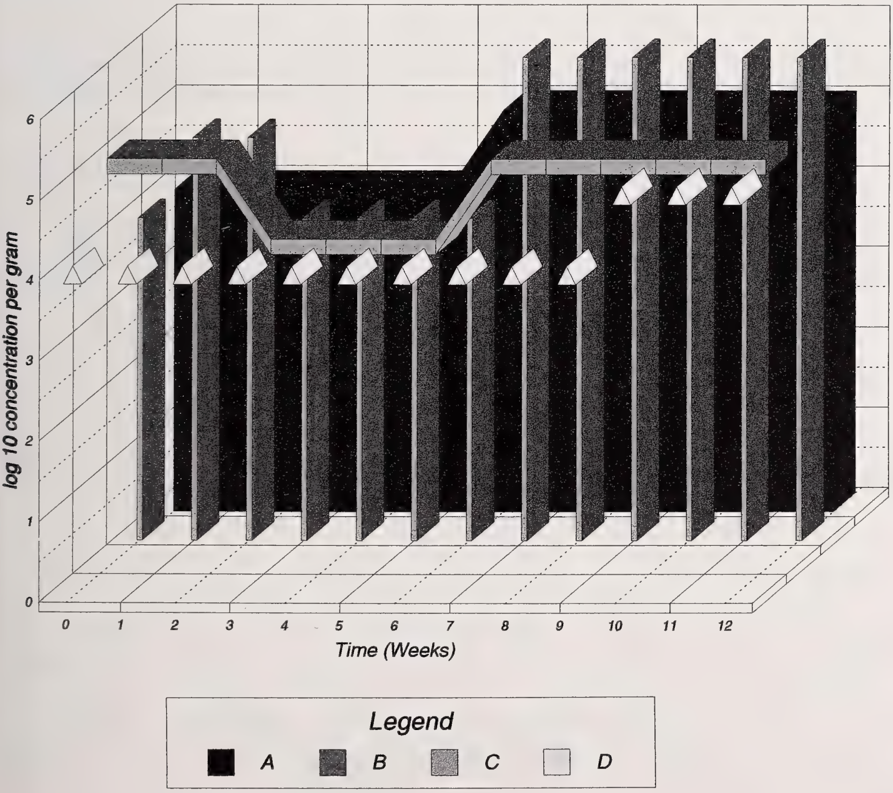
TABLE 1. Variable specifications for the biodegradation of used motor oil.

Variable	Type of Soil	Treatment	Oil
A	top soil	indigenous bacteria	oil
B	top soil	added bacteria and indigenous bacteria	oil
C	sterilized top soil	added bacteria	oil
D	sterilized top soil	none	oil

provided by Bushnell Haas growth medium (Haas and Haas, 1941). This experiment was duplicated to ensure the reproducibility of the results.

Bacterial counts—The amount of petrophilic and heterotrophic bacteria in the soil was determined weekly using Bushnell Haas and nutrient broth, respectively. 100 mg of soil were added to 0.9 ml of each growth medium. Ten-fold extinction dilution counts were then performed. After two weeks, each test tube was examined for growth.

Total recoverable petroleum hydrocarbon (TRPH) test—A TRPH test (EPA method number 9073) was conducted on the soil of each container at the zero time, six week, and twelve



Area Graph - Variable A Bar Graph - Variable B Line Graph - Variable C Scatter Graph - Variable D

FIG. 1. Mean cell count per gram of soil, variables A, B, C, and D.

TABLE 2. Results of the TRPH test. Amounts are averages shown in g oil per kg of soil.

	Variable A	Variable B	Variable C	Variable D
Amount zero time (g/kg)	101.0	101.0	101.0	101.0
Amount 6-week time (g/kg)	75.80	72.40	70.75	69.75
Amount biodegraded (g/kg)	25.20	28.60	30.25	31.25
Amount biodegraded, %	25.00	28.30	30.00	30.09
	Variable A	Variable B	Variable C	Variable D
Amount zero time (g/kg)	101.0	101.0	101.0	101.0
Amount 12-week time (g/kg)	77.50	80.85	100.1	83.75
Amount biodegraded (g/kg)	23.50	20.15	0.950	17.25
Amount biodegraded, %	23.30	20.00	0.900	17.10

week. Under the conditions of this experiment, the zero time sample had 101.0 g of hydrocarbons per kilogram of soil.

Analysis of Variance (ANOVA)—The Analysis of Variance test was conducted on the computer program MYSTAT. ANOVA was used to ascertain any significant differences in the TRPH results.

Polycylic aromatic hydrocarbon (PAH) test—A PAH test (utilizing EPA method number 3540A/8100, individual PAHs identified by gas chromatography / mass spectroscopy) was conducted weekly on the soil of each container.

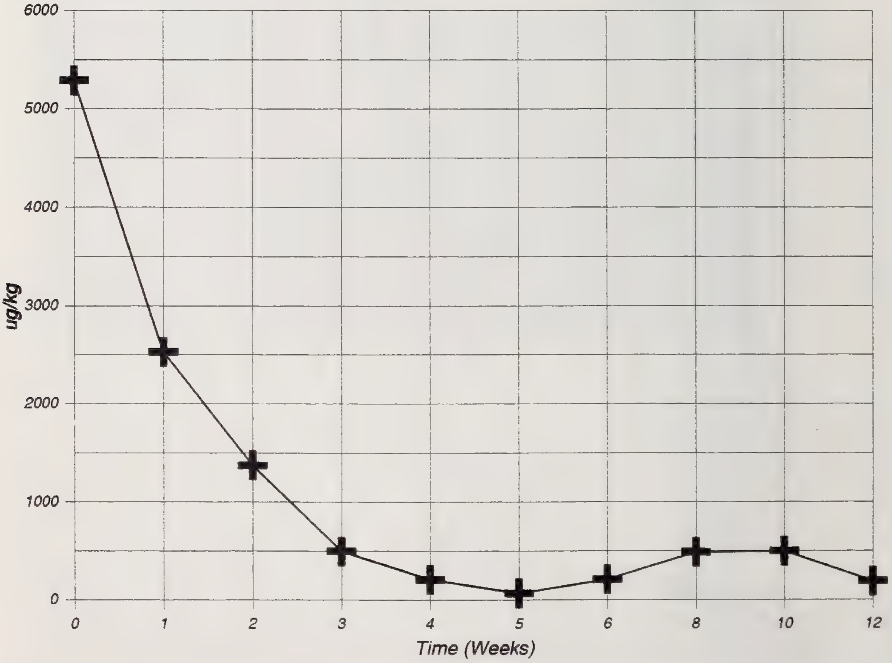


FIG. 2. Average of the level of naphthalene in variable A, (micrograms per kg of soil).

TABLE 3. Analysis of Variance (ANOVA) results on amount of oil biodegraded. P = Probability. A probability of 0.100 is significant.

6-week					
	Source	Sum of Squares	Mean-Square	F-Ratio	P
	Factor	42.205	14.068	0.436	0.739
	Error	129.03	32.258		
12-week					
	Source	Sum of Squares	Mean-Square	F-Ratio	P
	Factor	691.214	230.405	1.458	0.352
	Error	632.315	158.079		

Extraction procedure—Water-soluble materials were extracted from the soil of each container by adding 35 ml of sterile water to a sample of 200 g of contaminated soil. After twenty-four hours, 2 ml of the water was filtered through a 0.20 micrometer filter.

Ames (Salmonella mutagenicity) test—The Ames assay (Franson, 1992) was conducted weekly on soil samples taken from each container to test for potential carcinogens. This assay utilized 500 microliters of the extract from the extraction procedure mentioned above. Two different types of Salmonella bacteria, ATCC #29629 (testing for point mutations in which a single base at one point in the DNA is replaced with a different base), and ATCC #29630 (testing for frameshift mutations in which one or a few nucleotide pairs are deleted or inserted in the DNA), were used in this experiment (Tortora et al., 1995). Results are expressed as the

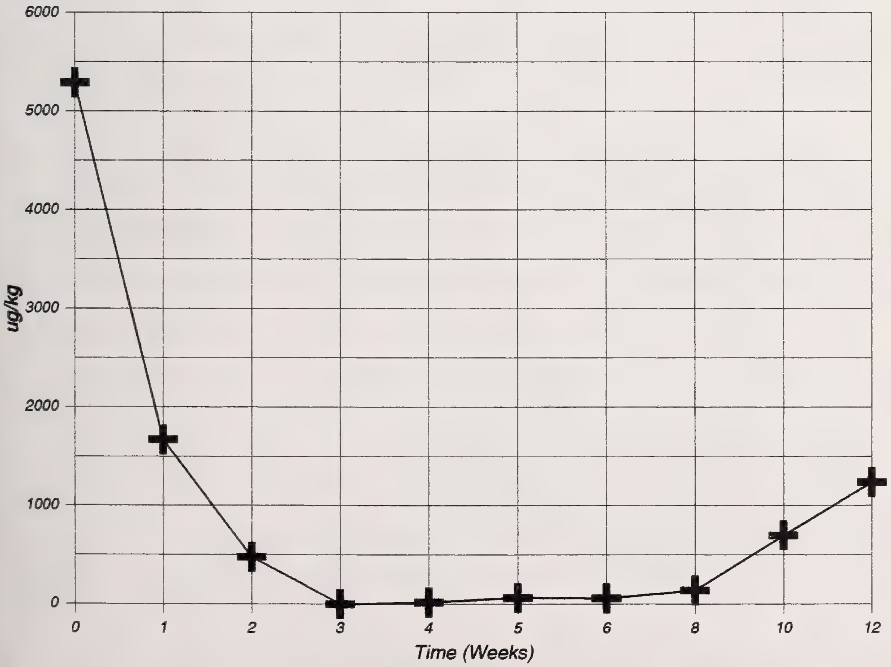


FIG. 3. Average of the level of naphthalene in variable B, (micrograms per kg of soil).

TABLE 4. Levels of 1-methylnaphthalene, 2-methylnaphthalene, and naphthalene in each variable. Amounts are shown in µg of PAH per kg of soil. (BDL = Below Detectable Limits)

Week:	0	1	2	3	4	5	6	8	10	12
Variable A1 & A2 (averages)										
1-methylnaphthalene	7670	8045	6525	370	1055	530	1510	2590	2000	1530
2-methylnaphthalene	8200	9300	8890	240	1495	740	2105	3840	2750	2320
naphthalene	5290	2530	1375	BDL	210	70	210	490	500	190
Variable B1 & B2 (averages)										
1-methylnaphthalene	7670	4405	2315	160	BDL	200	475	755	1250	3035
2-methylnaphthalene	8200	7835	4100	350	55	305	790	1280	1100	5200
naphthalene	5290	1670	480	BDL	BDL	65	60	140	BDL	1240
Variable C1 & C2 (averages)										
1-methylnaphthalene	7670	8275	3325	2100	4000	1300	2530	1450	1550	1160
2-methylnaphthalene	8200	10850	4290	2565	5985	1900	3960	2150	2150	1680
naphthalene	5290	4095	365	260	900	BDL	700	BDL	BDL	BDL
Variable D1 & D2 (averages)										
1-methylnaphthalene	7670	2395	2985	2435	3200	810	900	600	995	2395
2-methylnaphthalene	8200	3195	4315	3640	5020	1165	1420	1000	1530	3720
naphthalene	5290	735	350	215	650	110	255	BDL	305	530

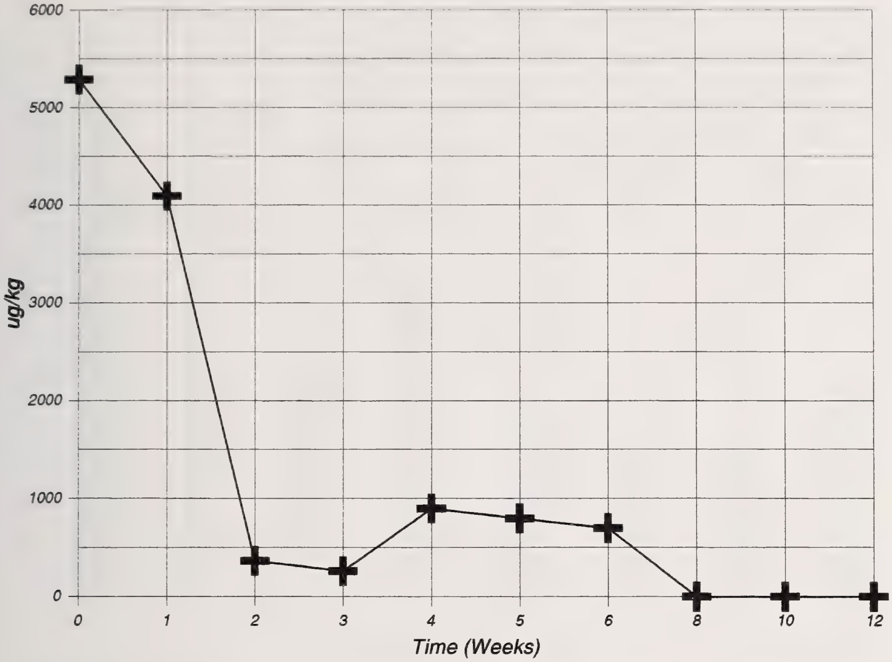


FIG. 4. Average of the level of naphthalene in variable C, (micrograms per kg of soil).

ratio of revertants to spontaneous revertants (control). A ratio of 1.5 or higher would indicate that a mutagen was formed.

RESULTS AND DISCUSSION—*Biodegradation of oil and bacterial counts*—The samples without added petrophilic bacteria (variables A and D) each initially contained 10^4 heterotrophic bacteria and 10^1 petrophilic bacteria per gram of soil. (Fig. 1) Over a five week period of time, the level of indigenous petrophilic bacteria in variable A reached the same level as the heterotrophic bacteria: 10^4/g. The indigenous petrophilic bacteria of variable D did not reach the same level as the heterotrophic until the eighth week.

The samples that received the known hydrocarbon-degrading bacteria (variables B and C) all had an approximate heterotrophic population of 10^4/g for the first six weeks. The heterotrophic population of variable B then increased to 10^6/g while the population of variable C increased to 10^5/g. The petrophilic population of both variables B and C started at approximately 10^2/g, and over three weeks reached the same level as the heterotrophs (10^4/g). Thus, one can conclude that the bacteria were relying primarily on the oil for a carbon source.

Total recoverable petroleum hydrocarbon (TRPH) test—The results obtained from the six week and twelve week samples are listed in Table 2.

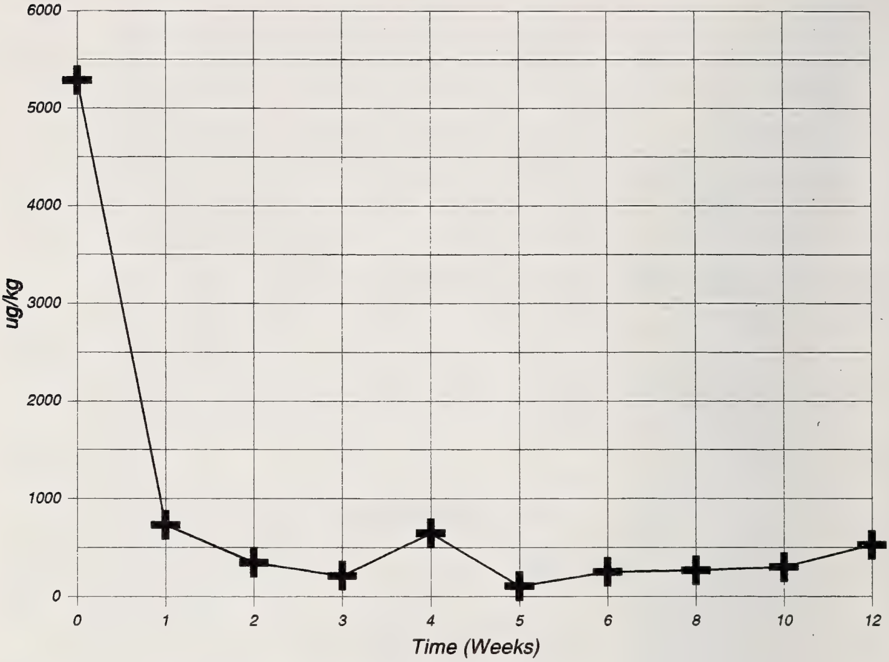


FIG. 5. Average of the level of naphthalene in variable D, (micrograms per kg of soil).

As shown in Table 2, the indigenous bacteria (variable A) biodegraded 25% of the oil in weeks zero through six. The added and indigenous bacteria (variable B) biodegraded 28% of the oil. The added bacteria in variable C biodegraded 30% of the oil, while variable D (sterilized soil) had the greatest amount of oil biodegraded: 31%. All of the twelve week percentages were lower, especially in variable C. A possible explanation for this phenomenon is the production of surfactants which allow bacteria to separate oil from soil particles. Therefore, the oil recovery was enhanced by the surfactant in the TRPH test.

Analysis of Variance (ANOVA)—The Analysis of Variance was used to determine the difference in TRPH degradation. Differences would be significant at P=0.100 to P=0.000. As shown in Table 3, however, there was no significant difference among the four factors (variables) for the six-week samples (P=0.739), or the twelve-week samples (P=0.352) under the conditions of this experiment. Regardless of the statistical analysis, mutagenic material was still produced in each of the samples (see Ames test).

Polycyclic aromatic hydrocarbon (PAH) test—Of the twenty-six compounds that could be measured by the PAH test, only naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene, showed a consistent pattern of deg-

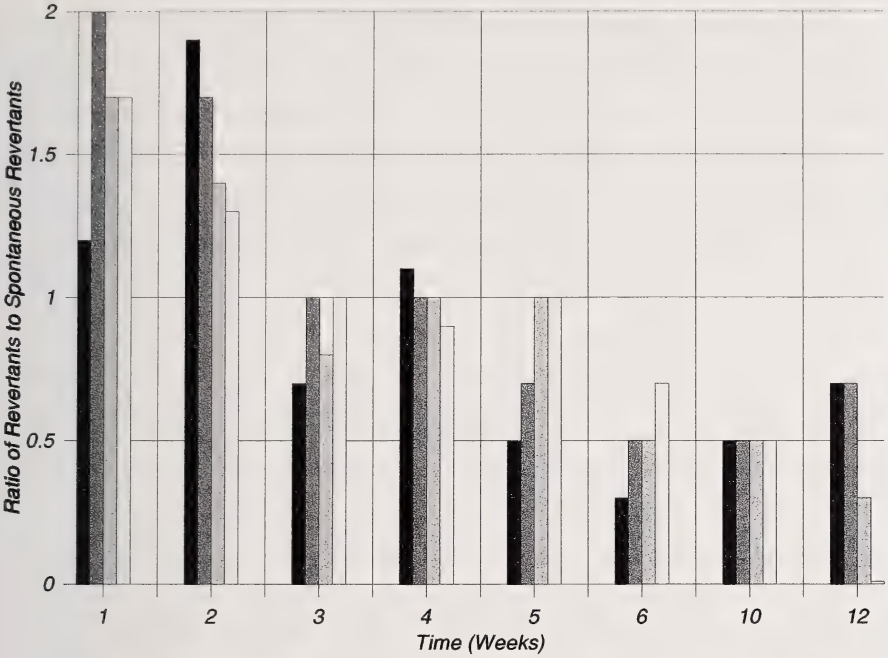


FIG. 6. Results of the Ames assay are expressed as the ratio of revertants to spontaneous revertants. A ratio of 1.5 or higher indicates that a mutagen was formed (Franson, 1992).

radation. In most of the samples, the level of naphthalene dropped considerably during the first two weeks, and was almost below detectable limits by the end of the third or fourth week. (Fig. 2–5) Thus, the hydrocarbon form of naphthalene was biodegraded into simpler constituents.

The levels of 1-methylnaphthalene and 2-methylnaphthalene reached their lowest levels during the fifth week in all samples tested. Interestingly, levels then returned to the original starting levels, suggesting that another substance was being biodegraded into 1-methylnaphthalene and 2-methylnaphthalene. (See Table 4)

Ames (Salmonella mutagenicity) test—During the first week, frameshift mutagens were detected in every sample. (Fig. 6) In the second week, only some samples had mutagens present, while the third week samples had none. The bacteria strain testing for point mutations produced sporadic mutagenic formations, and nothing can be concluded from this observation. Therefore, the water-soluble mutagen identified as a frameshift mutagen occurred in the first two weeks of the experiment and then disappeared in the third week.

Summary—The results of all six tests were compared. Through the comparison of the bacterial counts and the TRPH test, it was observed that the microbes were relying primarily on the oil for a carbon source. The results of the PAH and Ames tests were then correlated. It was discovered that the level of naphthalene dropped rapidly in the first two weeks, while simultaneously a water-soluble mutagen was formed. During the third week, the level of naphthalene was below detectable limits, and there were no mutagens detected. A possible explanation derived from these obsrvations is that the mutagenic material was produced from the biodegrading naphthalene.

One of the environmental consequences of discarding used motor oil onto soil is the contamination of groundwater. This study has shown that the indigenous bacteria as well as added hydrocarbon-degrading bacteria are capable of producing water-soluble mutagens in the soil. There are already many non-water-soluble mutagens found in used motor oil, but the water-soluble mutagen is a much greater hazard. Once it reaches the groundwater, it could easily spread and contaminate a large volume of water. It is recommended that a liner be placed under the soil to be remediated, preventing the spread of any mutagenic by-products.

Acknowledgments—I would like to thank Dr. Baugh for all of his help and his company for supplying me with many materials. I would also like to thank Dr. Binninger for his assistance with the Ames test and the Lambda assay, Michael Rentoumis and his staff at Envirodyne, Inc. for their assistance with the polycyclic aromatic hydrocarbon test and the total recoverable petroleum hydrocarbon test, and Dr. Charnetzky for encouraging my studies in the field of microbiology.

LITERATURE CITED

Claus, W. G. 1990. Understanding Microbes. W.H. Freemen and Company, New York, NY.

Colwell, R. R. and J. G. Leahy. 1990. Microbial Degradation of Hydrocarbons in the Environment. American Society for Microbiology, Washington DC.

Franson, M. A. H. (Manag. Ed.). 1992. Standard Methods for the Examination of Water and Wastewater, ed. 18, American Public Health Association, Washington DC.

Hong, P. 1991. Motor oil is dirty—but is it 'toxic'? Business Week, April 29, pp. 86.

Haas, L. D. and H. F. Haas. 1941. The utilization of certain hydrocarbons by microorganisms. J. Bact. 41:653.

Norris, R. D., R. E. Hichee, R. Brown, P. L. Mccarty, and L. Semprini. 1993. In-situ bioremediation of ground water and geological material: a review of technologies. United States Environmental Protection Agency, Aka, OK.

Riser-Roberts, E. 1992. Bioremediation of Petroleum Contaminated Sites. CRC Press, Inc., Boca Raton, FL.

Tortora, G. J., B. R. Funke, and C. L. Case. 1995. Microbiology: an Introduction. The Benjamin/Cummings Publishing Company, Inc., Menlo Park, CA.

Florida Scient. 60(1): 28–36. 1997
Accepted: July 23, 1996.

FIRST RECORD OF *ARTIBEUS JAMAICENSIS* LEACH (1821) FROM THE UNITED STATES

—*Philip A. Frank,* Florida Game and Fresh Water Fish Commission, Florida Keys Field Office, 2796, Overseas Highway, Suite 213, Marathon, Florida 33050

ABSTRACT: *The collection of two* A. jamaicensis *on Key West, Monroe County, Florida, an adult female on June 1, 1995 and an immature female on March 23, 1996, provides the first well-documented record of* Artibeus jamaicensis *in the United States. A review of the cumulative evidence suggests that* Artibeus jamaicensis *is established in Lower Keys of Florida.*

THE occurrence of *Artibeus jamaicensis* in the United States has long been a subject of debate (Lazell and Koopman, 1985; Humphrey and Brown, 1986; Lazell, 1989). On June 6, 1995 an adult *Artibeus jamaicensis* was collected from a chain link fence in a residential neighborhood in Key West. The specimen was still alive, and was taken to a wildlife rehabilitation center where it subsequently died. Measurements of the forearm are 55 mm. A second specimen of *A. jamaicensis* was collected on March 23, 1996, also on Key West. The individual was also found alive and taken to the wildlife rehabilitation center where it subsequently died. This individual was an immature female weighing 11.3 g with a forearm length of 35 mm. Both specimens are preserved in alcohol and are presently located at the Florida Game and Fresh Water Fish Commission, Florida Keys Field Office, Marathon, Florida. The collection of these individuals provides the first well-documented occurrence of *A. jamaicensis* in the United States.

A. jamaicensis was originally reported by Maynard (1883) who observed large flying bats in Key West during the winter, 1870. A specimen collected in Key West was later identified from a sketch as *A. perspicillatus* (=*jamaicensis*). The disposition of the original specimen is unknown and this record has been generally discounted (Layne, 1974). In February, 1983 several bats were flushed from a roof at East Martello Tower in Key West and one of the individuals was photographed. This photograph was identified as *A. jamaicensis* by Lazell and Koopman (1985) based on the lack of a tail and a visible leaf-nosed projection.

Humphrey and Brown (1986) later discounted this record as erroneous. They suggested that while the bat in the photograph was a member of the Phyllostomatidae, detail was sufficiently lacking for recognition to species level. They further discounted the record on the basis that no evidence of a resident population had been established, and concluded that the specimen in the photograph was a isolated waif.

Since the 1983 photograph, there has been no physical evidence of *A. jamaicensis* on the Keys. However, several unconfirmed reports of large tailless bats in the Keys have been generated, and these are well articulated by Lazell (1989). I have personally received accounts from reliable observers of large bats being spotted in the Keys. A biologist working at Fort

Zachary Taylor State Park in Key West informed me of several large bats in a cavity within the fort walls during the spring, 1995. These bats could not be found after the initial observation. A wetlands ecologist with the South Florida Water Management District reported flushing several large bats from a well shaft on No Name Key during the summer, 1995. Like the Fort Taylor report, no bats were present when I returned to document the records. As with the accounts provided by Lazell (1989), these observations were made by competent observers and I have little doubt that the animals in question were indeed bats. While these observations do not specifically support the presence of *A. jamaicensis* on the Keys, they do support the general theory that a large unidentified bat may indeed be resident on the Keys.

A. jamaicensis is one of the most widespread members of the genus *Artibeus,* ranging from Central Mexico to Paraguay and Central Brazil, throughout the Greater and Lesser Antilles, Trinidad and Tobago, and the Bahamas (Nowak, 1991). *A. jamaicensis* is tolerant of a wide range of habitat types including dry deciduous forest and tropical evergreen forests, and may roost in a variety of situations including buildings, caves, and hollow trees (Eisenberg, 1989). The wide geographical distribution and generalized habitat utilization of *A. jamaicensis* suggests this species is an excellent colonizer, and is obviously capable of extensive overwater dispersal. Colonization of the Keys by *A. jamaicensis* has most likely occurred from Cuba which lies approximately 100 km across the Straits of Florida.

It has been suggested that habitat suitable to support a resident population of *A. jamaicensis* is not available on the Keys. Humphrey and Brown (1986) concluded that the pronounced seasonality of the Keys climate may preclude a year-round fruit source, preventing the establishment of resident population of *A. jamaicensis.* However, *A. jamaicensis* occurs on other Caribbean islands with similar deciduous hardwood forest types such as many islands in the Greater and Lesser Antilles. *A. jamaicensis* is also highly mobile, traveling an average of 8 km nightly to forage in a study conducted in Mexico (Nowak, 1991). It is plausible that the extensive hardwood hammocks of the Lower Florida Keys provide enough suitable habitat to sustain at least a low density, highly mobile population (Lazell, 1989).

A. jamaicensis is strongly frugivorous, feeding on a wide variety of fruits including figs, mangoes, avocados, bananas, and palm seeds, but may also consume pollen, nectar, flower parts, and insects (Nowak, 1991; Eisenberg 1989). The fact that *A. jamaicensis* readily consumes cultivated fruits enables it to utilize a much wider niche and exploit a more diverse food source than if it were restricted exclusively to native fruiting tree species. Most islands throughout the Keys, especially Key West, have a profusion of introduced, cultivated fruit trees including sapodilla, avocado, mango, banana, and breadfruit to name only a few. The locality where the *A. jamaicensis* specimen referenced in this paper was collected is an old residential section of Key West with large numbers of mature fruit trees. The existence of this diverse array of exotic fruit trees may provide a year-round food source and could significantly enhance the ability of the Keys to support a resident population of frugivorous bats. A detailed study of fruiting phenology of Keys trees, both native as well as introduced, would shed light on the ability of fruit eating species such as *A. jamaicensis* to inhabit the Keys.

Based on the *A. jamaicensis* specimen from Key West, the long history of unsubstantiated reports of *A. jamaicensis* in the Lower Keys, and the availability of both habitat and a year-round food source, it is likely that *A. jamaicensis* is established on the Keys. Bats are generally secretive and difficult to observe, and it is not surprising that an *A. jamaicensis* colony has not yet been located. The recent discovery of several *Molossus molossus tropidorhynchus* colonies in the Lower Keys illustrates this principle well (personal observation).

ACKNOWLEDGMENTS—I am indebted to Becky Barron of Wildlife Rescue of Key West for having the foresight to save the *Artibeus* specimens. I thank Elizabeth Forys for reading an earlier version of this manuscript.

LITERATURE CITED

EISENBERG, J. F. 1989. Mammals of the neotropics. The northern Neotropics. Vol. 1. Panama, Colombia, Venezuela, Guyana, Suriname, French Guinea. University of Chicago Press. 449 pp.

HUMPHREY, S. R. AND L. N. BROWN. 1986. Report of a new bat (Chiroptera:*Artibeus jamaicensis*) in the United States is erroneous. Florida Scient. 49:262–263.

LAYNE, J. N. 1974. The land mammals of South Florida. In P.J. Gleason (ed.), Environments of South Florida: present and past. Memoir 2, Miami Geol. Soc. 452 pp.

LAZELL, J. D. 1989. Wildlife of the Florida Keys: a natural history. Island Press, Washington D.C., 250 pp.

——— AND K. F. KOOPMAN. 1985. Notes on bats of Florida's lower Keys. Florida Scient. 48: 37–41.

MAYNARD, C. 1883. The mammals of Florida. Quart. Jour. Boston Zool. Soc. 2:1–8.

NOWAK, R. M. 1991. Walker's mammals of the world. 5th Ed., Vol. 1., Johns Hopkins Press, Baltimore, MD. 642 pp.

Florida Scient. 60(1): 37–39. 1997
Accepted: July 23, 1996

RESPIRATORY STRATEGIES OF A NON-NATIVE FLORIDA CICHLID, *CICHLASOMA OCTOFASCIATUM*

CLAIRE O. OBORDO AND LAUREN J. CHAPMAN[1]

Department of Zoology, University of Florida, Gainesville, Florida 32611, U.S.A.

ABSTRACT: *Tolerance to low oxygen is one factor that may limit the colonization of some freshwater habitats by non-native fishes. This study examined the low oxygen tolerance of the Jack Dempsey,* Cichlasoma octofasciatum, *an introduced cichlid recorded from many sites in Florida. A suite of parameters that may influence tolerance to low oxygen conditions were measured including: metabolic rate, critical oxygen tension, respiratory behavior, and total gill filament length. Several lines of evidence suggest that* C. octofasciatum *has a relatively high tolerance to low oxygen conditions which may facilitate exploitation of hypoxic waters. In response to progressive hypoxia,* C. octofasciatum *uses aquatic surface respiration (ASR); however, this behavior was only initiated when oxygen levels were extremely low (<5 mm Hg), suggesting that other well-developed physiological mechanisms compensate for hypoxia above this level. These include a low metabolic rate, a large total gill filament length, and a low critical oxygen tension which averaged 14.9 mm Hg.*

THE INTRODUCTION of non-native fishes into new habitats can have a variety of impacts including predation on indigenous species, hybridization, introduction of disease and parasites, competition for food with native species, crowding, the alteration of existing food webs, and environmental effects (Welcomme, 1984). Since fish introductions will continue to be made either for biological management or by accidental transfer, it is important that we learn to predict the consequences of introductions based on environmental characteristics. In a conservation context, ecologists face several critical issues with respect to the biology of non-native species. Of particular importance is understanding what limits the habitat exploitation of introduced species and what limits their dispersal from the site of introduction into new areas. There may be particular characteristics of the invaded community that minimize or facilitate dispersal and colonization. Such information can be used to predict long-term trends, manage or manipulate barriers, and to formulate recommendations to minimize deleterious effects should future introductions occur.

Florida, with its subtropical climate, abundant rainfall, vast areas of wetlands, peninsular shorelines, and high concentration of tropical fish farms, harbors more introduced fish species than any other state (Courtenay and Robins, 1973; Courtenay, 1993). Florida public waters are currently home to over 23 established exotic species, 9 formerly established species, and 38 species collected but not known to be established (Courtenay et al., 1986; Courtenay et al., 1991).

---

[1] Author to whom correspondence should be directed

Fishes of the family Cichlidae account for the majority of established fishes in Florida. Thirteen species of cichlids currently reside in Florida waters (Courtenay et al., 1991). Many have extended their ranges through dispersal and are becoming important components of numerous lakes, streams, and canals in the state (Courtenay et al., 1974; Hogg, 1976). One factor which may limit the potential range of non-native fishes in northern Florida is their tolerance to cold temperatures (Shafland and Pestrak, 1982). However, the availability of dissolved oxygen may also limit habitat quality for fishes (Roberts, 1975; Kramer, 1983; Saint-Paul and Soares, 1987). For introduced fishes, tolerance to low oxygen may affect colonization and dispersal, particularly in wetlands, small intermittent streams, springs, and polluted canals of Florida which may experience chronic, seasonal, or diel hypoxia (e.g., Kushlan 1979, 1980; Woodruff, 1983).

Oxygen limitations have produced varied evolutionary responses by fishes such as the development of air-breathing organs, the ability to carry out aquatic respiration at the air-water interface, anaerobic metabolism, large gill surface area, and high hemoglobin counts (Liem, 1980; Kramer, 1983; Chapman and Liem, 1995; Chapman et al., 1995). These different adaptations have costs and benefits which vary with ecological conditions, and may affect the abilities of introduced species to establish at the site of introduction or disperse to new habitats. Cichlid fishes show varied tolerance to low oxygen and exhibit many strategies for coping with low oxygen stress. In response to severe hypoxia, some cichlids use aquatic surface respiration (ASR) at the air-water interface, where diffusion produces a thin layer of well-oxygenated water, despite oxygen scarcity in the rest of the water column (Kramer and McClure, 1982; Verheyen et al., 1994; Chapman et al., 1995). Studies of gill morphology in a variety of cichlids from Lake Victoria have demonstrated large gill surface area in some species suggesting high tolerance to low oxygen (Galis and Barel, 1980; Hoogerhoud et al., 1983). And, Galis and Smit (1979) found a lower critical oxygen tension in the cichlid *Haplochromis augustifrons,* a species which feeds in oxygen-poor mud, than in *Haplochromis elegans,* a species which feeds primarily in oxygen-rich deposits.

We examined the respiratory behavior and physiological ecology of the Jack Dempsey, *Cichlasoma octofasciatum,* an introduced cichlid recorded from many sites in Florida. To facilitate comparison with published results on the tolerance of other cichlids, we examined behavioral, physiological, and morphological adaptations which may promote survival in hypoxic waters. These included behavioral response to progressive hypoxia, metabolic rate, critical oxygen tension, and total gill filament length.

METHODS—*Study species and site*—The Jack Dempsey, *Cichlasoma octofasciatum,* is endemic to the Atlantic slope drainages of Central America from Veracruz, Mexico (Rio Paso

San Juan) to the Rio Ulua basin of north-western Honduras, and also in the Yucatan Peninsula (Miller, 1966). Adults reach sizes up to 135 mm SL. *C. octofasciatum* is omnivorous, feeding opportunistically on fish, invertebrates, and vegetation (Jennings, 1986). Multiple introductions in Florida beginning in the 1960s (Courtenay et al., 1986; Courtenay, 1993) have resulted in established populations in Dade County (Courtenay et al., 1974; Kushlan and Lodge, 1974), Hillsborough County (Courtenay et al., 1974), Brevard County (Dial and Wainright, 1983), and Alachua County (Jennings, 1986). The northernmost record for the species is Gainesville, Alachua County, Florida (29° 40′ N, 82° 20′ W, Jennings, 1986) where reproducing populations inhabit small creeks on the University of Florida Campus. Jack Dempseys found in Alachua and Brevard counties may have been released as pet fish by fish hobbyists, whereas the populations of Jack Dempseys in Dade and Hillsborough counties were probably released or escaped from fish farms (Courtenay et al., 1986; Courtenay and Williams, 1992). The effects of these introductions are largely unknown; however, it appears to be a highly aggressive species and a potential competitor for food and spawning sites with indigenous centrarchids (Nico, 1995).

Individuals of *C. octofasciatum* were collected in November 1994 from an established population on the campus of the University of Florida, Gainesville, Alachua County. Twenty-three specimens (5.3 to13.1 cm, TL) were captured using modified minnow traps set at eight sites along a 1.1 km creek that originates on the northeast side of the University campus and meanders southwest to feed Lake Alice, a 16.2 ha wildlife sanctuary. Further details on the study creek are provided by Jennings (1986). Water temperature and dissolved oxygen were measured at each site using a YSI Model 57 meter and ranged from 20° to 24°C and 4.0 to 7.9 mg l^{-1}, respectively.

Respiratory behavior—To quantify the behavioral response of *C. octofasciatum* to progressive hypoxia, ten individuals (7.9 to 9.1 cm TL; 8.52 ± 0.05 cm, mean TL) were removed from the sample stock of collected fish and transferred to a glass aquarium (75 × 32 × 31 cm, water depth = 25 cm). The experimental tank was divided into three compartments separated by screen partitions: two side compartments (10 cm wide) and a central compartment (55 cm wide). The central compartment contained the fish and low cover, and the two smaller compartments contained heaters and airstones. A blind permanently positioned in front of the aquarium permitted observations through a small viewing port. The experimental tank was maintained at 24.2° to 24.8°C, and the fish were fed flake food.

Nitrogen was bubbled into the two side compartments to lower the oxygen content (Gee and Gee, 1991; Chapman et al., 1994, 1995), while not disturbing the water surface in the main compartment. To create extreme hypoxia (<1.0 mg l^{-1}), small amounts of sodium sulfite were added to the water (Lewis, 1970; Gee and Gee, 1991; Chapman et al., 1994, 1995). Oxygen was lowered progressively over a 2 to 4 hour period until oxygen levels reached <0.2 mg l^{-1}. If any individual lost equilibrium, the fish was quickly removed from the experimental tank and placed in well-oxygenated water to recover. Each trial ended when all of the individuals in the aquarium had been observed to use aquatic surface respiration.

The following parameters were recorded from behind the blind at 15-minute intervals: gill ventilation rate (number of ventilations in a 15-second period recorded for at least 6 fish), number of fish using aquatic surface respiration (ASR, recorded every 10 seconds for 100 seconds), number of fish showing signs of activity (any directed movement, recorded every 5 seconds for 50 seconds), and the number of fish that were buccal bubble holding. Observations of aggression were also noted. Dissolved oxygen concentration (± 0.01 mg l^{-1}) and temperature (± 0.1°C) were measured with a YSI Model 50B oxygen meter after the behavioral observations were recorded. Oxygen concentration values were converted to partial pressure of oxygen (P_{O2}) in mm Hg, using standard tables (Davis, 1975). The oxygen levels at which 10% (ASR_{10}) and 50% (ASR_{50}) of the fish performed ASR were estimated from plots of the percentage of fish using ASR and the P_{O2} (following Kramer and McClure, 1982; Chapman et al., 1995). Six experimental trials were conducted on the same 10 fish over a period of three weeks with at least one day between trials. After each run, the aquarium was returned to normoxic conditions.

Metabolic rate and critical oxygen tension—Differences among species in their tolerance to low oxygen may be attributed in part to differences in their metabolic rates (Hlohowskyj and Wissing, 1987). Most fishes regulate metabolic rate over a range of dissolved oxygen concentrations; but at some point, reduction in oxygen will produce a shift from a metabolic rate that is independent of oxygen concentration to one that is dependent on oxygen concentration. This level is referred to as the critical oxygen tension (Ultsch et al., 1978; Hlohowskyj and Wissing, 1987). We measured both metabolic rate and critical oxygen tension using a closed respirometer for fishes acclimated to normoxia. Metabolic rate was determined as routine oxygen consumption (rates during random movement under experimental conditions (Saint-Paul, 1984)), and critical oxygen concentration was determined through graphic interpretation.

Nine individuals were selected from the *C. octofasciatum* stock to maximize the range in body size (3.74 to 41.90 g, 5.3 to 13.1 cm TL). An individual fish was placed in a dark chamber with a bubbler and a mesh net covering the night before an experimental trial. The chambers were held in an aquarium water bath to maintain constant temperature; trials were initiated the following morning and lasted an average of 6.7 hrs. Chamber size was varied to minimize the volume of water while not crowding the fish. Water temperature averaged 24.0 °C (range = 23.7 to 24.4 °C). At the start of these metabolic measurements, the bubbler was removed from the chamber, and the flask was then sealed with a tightly fitting oxygen probe connected to a YSI Model 600 multi-parameter, water quality measurement and data collection system. This meter was programmed to take measurements of temperature and dissolved oxygen in the closed container at 5-minute intervals and display plotted values throughout the trial. Once the critical oxygen tension was detected on the computer generated plots, the experiment was terminated, and the water in the chamber was returned to normoxia. Following each trial, the total length and weight of the fish were recorded.

Oxygen consumption rate, M_{O2} (mg O_2/h), was calculated following Cech (1990):

$$M_{O_2} = \frac{(C_{O_2(A)} - C_{O_2(B)})V}{T};$$

where $C_{O2(A)} = O_2$ concentration (mg l^{-1}) in the flask at the beginning of the measurement period, $C_{O2(B)} = O_2$ concentration in the flask at the end of the measurement period, V = volume of the respirometer (L), and T = time elapsed during the measurement period (h). We used a 10 to 20 minute measurement period for calculation of M_{O2} to calculate the total metabolic rate of the fish in mg O_2/hr and mass specific metabolic rate (mg O_2/g of fish/hr). In general, metabolic rate was calculated using data collected at least one hour after the oxygen probe was placed into the chamber and approximately 1/2 hour before the calculated critical oxygen tension (P_c). The critical oxygen tension (or critical partial oxygen pressure), P_c, was estimated by visual interpretation of the relationship between P_{O2} (mm Hg) and V_{O2} (mg of O_2/g/hr) and 2), and using a BASIC program developed by Yeager and Ultsch (1989). This program is designed to fit two regression lines to the data set. The first line is drawn when the metabolic rate (V_{O2}) is constant over a period of time. The second regression line is drawn once V_{O2} becomes dependent on oxygen tension. The intersection of the two regression lines is used to estimate the critical oxygen tension.

Gill morphology—We compared the gill morphology of *C. octofasciatum* to other cichlids for which morphological measurements were available in the literature. The morphological parameters most easily and accurately measured for large numbers of small fish are total gill filament length and filament number. Total gill filament length shows a general correlation with total gill surface area (Palzenberger and Pohla, 1992). These parameters were measured for 10 *C. octofasciatum* (7.0 to 12.9 cm TL) preserved in paraformaldehyde (35 g/L) using standard methods for quantifying gill filament length (mm) and filament number (Muir and Hughes, 1969; Hughes, 1980, 1984). For each fish, the branchial basket was removed, and the four gill arches from the left side of the basket were separated. For each hemibranch of the four gill arches, the length of every 5th gill filament was measured. Calculations of total gill filament length were weighted according to Hughes (1984). Two successive measurements (e.g., 5th and

10th filament) along a hemibranch were averaged and then multiplied by the number of filaments in the section between the two filaments.

RESULTS—*Respiratory behavior*—In response to severe hypoxia, the Jack Dempsey uses aquatic surface respiration at the air-water interface, ventilating its gills with water from the surface film. ASR was initiated when oxygen levels fell below 5.5 mm Hg (0.3 mg l^{-1}) and then increased quickly to account for more than 85% of their time at P_{O2} <3 mm Hg (<0.15 mg l^{-1}). ASR_{10} and ASR_{50} occurred at 5.3 mm Hg (± 1.5 mm Hg, SD, n=6 trials) and 3.6 mm Hg (± 1.0 mm Hg, SD, n=6 trials), respectively. Because they swam at the surface during ASR, there was a general increase in activity over the course of the trial.

Gill ventilation rates increased with decreasing P_{O2} ($r = -0.80$, $P = 0.006$) from an average of 21.7 ventilations/15 sec at higher oxygen levels (75 to 108 mm Hg, 4 to 6 mg l^{-1}, n = 5 trials) to an average of 31.6 ventilations/15 sec under extreme hypoxia (<4.5 mm Hg, <0.25 mg l^{-1}, n = 6 trials). Gill ventilation rates during ASR ranged from 27 to 35 ventilations/15 sec. Whenever possible, gill ventilation rates were recorded for fish using ASR and fish not at the surface during the same observation period. ASR values (mean = 33.9 ventilations/15 sec, n=4 bouts) were higher than non-ASR values (mean = 28.6 ventilations/15 sec). There were also noticeable differences in the nature of the opercular movement. Many shallow ventilations occurred at the onset of respiratory stress, while deeper ventilations were observed under increased hypoxia.

C. octofasciatum moved actively at the surface during ASR using both active forward and backward motion. Buccal bubble holding was extremely rare, witnessed only twice during all trials. Aggression (e.g., chases) appeared to accelerate with decreasing P_{O2}, except in cases of extreme hypoxia. Aggression was observed repeatedly in trials, although no single, dominant individual was recognized.

Metabolic rate and critical oxygen tension—The mass specific metabolic rate of *C. octofasciatum* (n = 9) ranged from 0.055 to 0.13 mg O_2/g of fish/hr (mean = 0.096, SD = 0.022). Total metabolic rate was positively correlated with body weight (bilogarithmic plot: r = 0.944, P<0.001, Figure 1); however all points fall below the standard curve for metabolic rate and body weight for freshwater fishes derived from Winberg (1961, Figure 1). Calculations of critical oxygen tension (P_c) based on visual interpretation of the plots of V_{O2} versus P_{O2} showed less variation than the computer-calculated values ($SD_{vi} = 0.25$, $SD_c = 5.63$); however, both means were similar. Critical oxygen tension values based on the BASIC computer program (Yeager and Ultsch, 1989) averaged 14.91 mm Hg (0.82 mg l^{-1}) and ranged from 6.6 to 26.4 mm Hg; while values derived from visual estimation averaged 14.39 mm Hg (0.79 mg $l^{-1)}$ and ranged from 12.0 to 23.0 mm Hg.

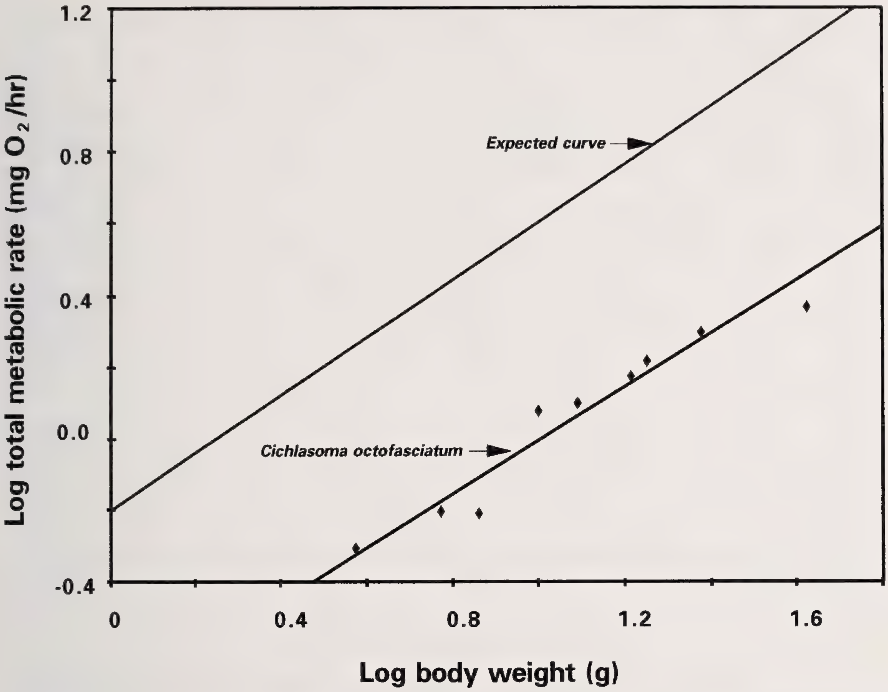


FIG. 1. Relationship between routine metabolic rate (at 24 °C) and body weight for nonnative *Cichlasoma octofasciatum* from a stream in Gainesville, Florida. The expected curve for freshwater fishes was derived from Winberg (1961).

Gill Morphology—The total gill filament length (TFL) of *Cichlasoma octofasciatum* (body weight range = 7.9 to 47.8 g) ranged between 2840 and 6491 mm and increased with body mass (bilogarithmic plot: $r = 0.99$ $P<0.0001$, Figure 2). The number of filaments ranged from 83 to 120 per hemibranch, but varied among hemibranchs and with body size.

DISCUSSION—*Cichlasoma octofasciatum* demonstrates a diversity of respiratory strategies that may facilitate survival in oxygen scarce waters and permit access to wetland areas, temporary ponds, and other environments that experience diel or seasonal hypoxia. *C. octofasciatum* have been recorded from dense littoral vegetation in canals and streams in Florida (Dial and Wainright, 1983; Obordo and Chapman, unpublished data). The persistence of this species on the University of Florida campus, from its discovery in 1982 (Jennings, 1986) through more than a decade, and its continued persistence in other Florida waters may be attributed, in part, to the Jack Dempsey's ability to withstand hypoxia. Of the suite of characters that we considered as potential adaptations to low oxygen, a low metabolic rate, a low critical oxygen tension, and relatively large gills may contribute to its

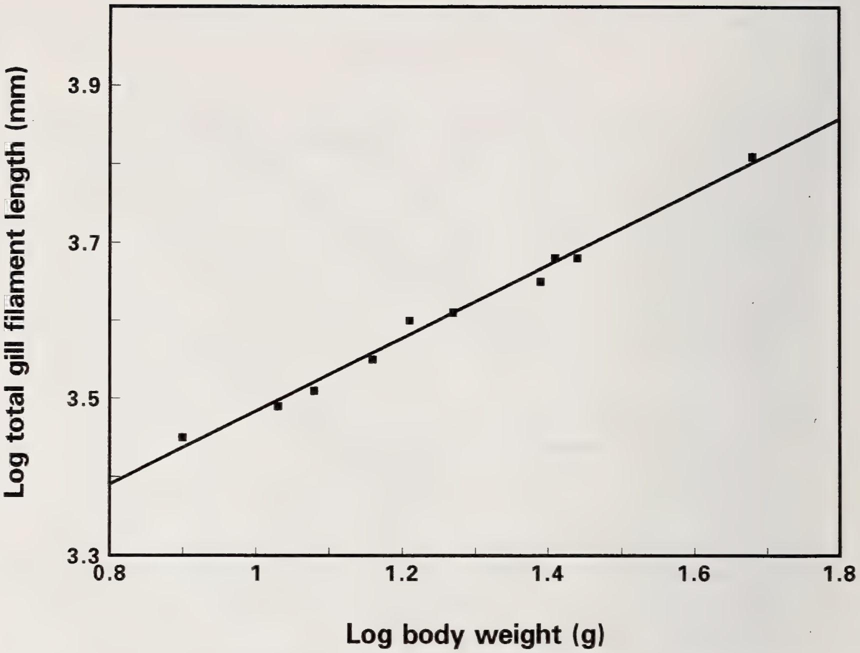


FIG. 2. Bilogarthmic plot of total gill filament length (estimate for all arches combined) and body mass for *Cichlasoma octofasciatum* from a stream in Gainesville, Florida.

ability to tolerate hypoxia and permit an extremely low threshold for aquatic surface respiration.

Behavioral strategies—The ability of *C. octofasciatum* to withstand extremely low P_{O2} levels before initiating aquatic surface respiration suggests that other well-developed physiological mechanisms compensate for hypoxia above the ASR threshold. P_{O2} levels fell below 5.5 mm Hg (<0.3 mg l^{-1}) before ASR was initiated. This threshold is low when compared to other tropical fishes. Kramer and McClure (1982) found that the ASR_{50} level averaged approximately 16 mm Hg in 27 species of non-air breathing fishes. Although aquatic surface respiration is a widespread adaptation to oxygen scarcity among non-air breathing fishes from periodically hypoxic habitats (Gee et al., 1978; Kramer and McClure, 1982; Chapman et al., 1995; Winemiller, 1989), the use of this behavior has costs including large temporal costs in many species and a high risk of aerial predation. When oxygen levels approach zero, the time spent in ASR can increase to over 90% in many species, including several cichlids (Kramer and McClure, 1982; Chapman et al., 1994; Chapman and Liem, 1995; Chapman et al., 1995). Fish using ASR may also present more visible targets to aerial predators than if they were deeper in the water column. Kramer and co-workers (1983) demonstrated that the risk of capture increased for fishes using ASR when exposed to predation by a green heron (*Butorides striatus*) under controlled laboratory conditions. Selection to minimize these costs may relate to the development of morphological and physiological traits that maximize oxygen uptake and minimize the threshold for aquatic surface respiration.

Both the pattern of gill ventilations and behavior during ASR suggest that aquatic surface respiration is not extremely efficient in this species. In general, gill ventilation rates of *C. octofasciatum* were higher during ASR than just prior to the initiation of ASR. In other species, gill ventilation rates often decrease with the initiation of ASR (Chapman et al., 1995; Olowo and Chapman, 1996), which suggests that aquatic surface respiration increases the efficiency of oxygen uptake. In addition, many other species of fishes that use ASR exhibit bubble holding behavior, whereby a bubble of air is held more or less continually in the buccal cavity during ASR, and exchanged frequently (Gee and Gee, 1991; Chapman and Liem, 1995; Chapman et al., 1995). Water is passed around the bubble during ASR, potentially increasing the oxygen content of the ventilated water and/or contributing to lift (Gee and Gee, 1991; Chapman and Liem, 1995). In *C. octofasciatum,* bubble holding was present, but very infrequent, suggesting that this behavior is not well developed in this species. Some fishes that use aquatic surface respiration swim continuously at the surface film during ASR. Chapman and co-workers (1994), referred to this as ram-assisted ASR in their description of the respiratory behavior of *Synodontis afrofischeri,* a species which uses continuous active forward motion at the surface during ASR. This behavior potentially increases the efficiency of ASR by passing more fresh surface water across the gills and may also assist with hydrodynamic lift (Chapman et al., 1994). In other species, active movement at the surface may be directed forward or backward. Chapman and co-workers (1995) found that seven of twelve East African cichlids swam continuously across the surface during ASR; however, much of the movement was backwards. They suggested that although backward motion is not likely to contribute to lift or force more well-oxygenated water over the gills, it may expose the fish to new surface film. In *C. octofasciatum,* active movement at the surface during ASR was not conducted in a well coordinated manner; which again may suggest relatively inefficient ASR. Aggressive behaviors in *C. octofasciatum* were high, and social grouping was rarely observed. This may have contributed to the pattern of movement at the surface film.

The increase in gill ventilation rate with ASR, lack of consistent bubble holding, and lack of coordinated behavior during ASR, all suggest that aquatic surface respiration behavior is not well-developed in *C. octofasciatum.* Other physiological and morphological adaptations including large gills, a low metabolic rate, and a low critical oxygen tension may account for the ability of *C. octofasciatum* to tolerate extreme hypoxia and permit an extremely low ASR threshold in this species.

Physiological strategies—A low metabolic rate and a low critical oxygen tension are two physiological strategies that may permit a fish to withstand extreme hypoxia. The metabolic rate of *C. octofasciatum* was very low compared to the standard curve for freshwater fishes derived from Winberg (1961) and lower than many of the values recorded for 10 East African cichlid species by Verheyen and co-workers (1994). Winberg (1961) also presents an equation for cyprinodont fishes which have metabolic rates below his predicted line for freshwater fishes. The metabolic rate for *C. octofasciatum* also falls below the cyprinodont line. The critical oxygen tension of *C. octofasciatum* is much lower than values reported by Verheyen and co-workers (1994) for species of African cichlids found in moderately to well-oxygenated habitats. Verheyen and co-workers (1994) reported average critical tensions of 47.2 mm Hg and 38.5 mm Hg for two species of cichlids that live in well-oxygenated rocky littoral areas of Lake Tanganyika (*Tropheus moorii* and *Eretmodus cyanostictus,* respectively) and a critical tension of 26.2 for a *Melanochromis auratus,* a cichlid from the well-oxygenated rocky littoral area of Lake Malawi. Three species of cichlids that inhabit moderately well-aerated water also showed higher values than *C. octofasciatum* (25.1 mm Hg for *Astatotilapia burtoni* from Lake Tanganyika, 36.1 for *Dimidiochrois compressiceps,* and 26.5 for *Nimbochromis venustus,* both from Lake Malawi, Verheyen et al., 1994).

Morphological strategies—Some water breathing fishes decrease the threshold for ASR by having very efficient oxygen uptake mechanisms. One such mechanism is a large respiratory surface area. For example, the Amazonian fish, *Colossoma macropomum,* is subject to seasonal hypoxia in the varzea lakes of the Central Amazon. This species has an extremely large respiratory surface area relative to other freshwater fishes, and exhibits a very low threshold for ASR (Saint-Paul, 1984). Chapman and Liem (1995) found significant differences in the total gill filament length between populations of an African cyprinid, *Barbus neumayeri.* In the extremely hypoxic waters of a papyrus swamp in Uganda, *B. neumayeri* had gills that were 35% larger in total gill filament length than a nearby population from a well-oxygenated everflowing section of the same drainage. And, in a comparison of two closely related cichlids from Lake Victoria, Hoogerhoud and co--workers (1983) found that the gill area was 1.6 times larger in *Haplochromis iris* than in *H. hiatus.* They suggested that this difference was related, at least in part, to the severe hypoxic conditions confronted by *H. iris* during stratification.

Galis and Barel (1980) presented gill morphology data for more than 80 species of East African lacustrine cichlids. Total gill filament lengths of *Cichlasoma octofasciatum* were generally higher than other African cichlids of equal or greater size. A Jack Dempsey, which was 26 g, had gills 39% larger in total filament length than "*Haplochromis*" *longirostris* and *Lamprologus elongatus* of similar size and 62% larger than "*Haplochromis*" *schubotzi.* The smallest Jack Dempsey (11 g) had a total gill filament length that was 16% larger than two species of East African cichlids (*Thoracoch-*

romis petronius and "*Haplochromis*" *macrognathus*) and 30% larger than "*Haplochromis*" *schubotziellus* of equivalent size. The observed difference in total gill filament length between *C. octofasciatum* and other African cichlids suggests a large gill surface area in *C. octofasciatum* relative to other African cichlids. However, the density and area of gill lamellae vary greatly among cichlids, and a more detailed morphological analysis of *C. octofasciatum* would be necessary to determine differences in gill surface area between this species and other cichlids.

Palzenberger and Pohla (1992) reviewed literature data available on the gill morphology of fishes. From their data set for 28 water-breathing freshwater species, they extracted the mean slope of significant regressions for gill morphological parameters and body weight. And, in addition, they set the lowest and highest mean values within each range to 0% and 100% to create a range of values for each gill parameter. This permitted them to express the values of a species as a percentage within the range of values for freshwater fishes. For total gill filament length, Jack Dempseys fall in the upper 35% of the range for freshwater fishes analyzed by Palzenberger and Pohla (1992), indicating a relatively large gill size for this species.

A consideration of the combination of total gill filament length and metabolic rates for *C. octofasciatum* supports high tolerance to low oxygen. The gill surface area of fishes is assumed to correlate with the ratio of metabolic oxygen demands to oxygen content of the habitat (Palzenberger and Pohla, 1992). In their review, Palzenberger and Pohla (1992) found that oxygen content alone did not explain a significant component of the variance in gill area among species. However, the ratio of activity level to oxygen content of their environment could differentiate species with high requirements relative to their oxygen supply from those with lower ratios. We found *C. octofasciatum* to have a relatively low metabolic rate and a large total gill filament length, which suggests that any increase in the oxygen uptake efficiency afforded by large gills may reflect a requirement of the environment, rather than sustaining high activity levels.

Implications for the distribution of Cichlasoma octofasciatum—The physiological and morphological strategies exhibited by *C. octofasciatum* for dealing with low oxygen conditions may permit an extremely low threshold for aquatic surface respiration and facilitate exploitation of hypoxic waters. The distribution of *C. octofasciatum* in Florida's subtropical wetlands and streams supports their abilities to deal with potentially hypoxic and highly fluctuating environments. It is interesting that the introduced populations of *C. octofasciatum* in Florida do not appear to be exhibiting range expansion (Nico, 1995). Shafland and Pestrak (1982) examined the temperature tolerance of fourteen non-native fishes in Florida. They suggested that the relatively low lethal temperature for *C. octofasciatum* when compared to temperature isotherms for Florida indicated suitable winter stream temperatures for this species south of Jacksonville. Factors such as their relatively low lethal temperature and low critical oxygen tension may have contributed to the long-term survival of *C. octofasciatum* where it has been introduced; however, other factors may limit range expansion.

Acknowledgments—Thanks to G. Burgess, L. Nico, F. Nordlie, C. Timmerman, S. Walsh, and J. Williams for ideas and information on the number, distribution, and ecology of non-native cichlids in Florida. We thank B. Boylan, M. Hart, and P. Schofield for assistance with the collection of specimens, D. Haney and A. Keiter for assistance with the analyses of metabolic rate data, and C. Chapman and A. Keiter for comments on an earlier version of the manuscript. Permission to collect *Cichlasoma octofasciatum* was obtained from the Florida Game and Freshwater Fish Commission (permit no. F-573).

LITERATURE CITED

Cech, J. J. 1990. Respirometry. Pp. 335–362. In: Schreck, C.B. and P.B. Moyle (eds.). Methods for Fish Biology. American Fisheries Society, Bethesda, Maryland.

Chapman, L.J. and K.F. Liem. 1995. Papyrus swamps and the respiratory ecology of *Barbus neumayeri*. Env. Biol. Fish. 44:183–197.

———, L.S. Kaufman, and C.A. Chapman. 1994. Why swim upside down?: A comparative study of two mochokid catfishes. Copeia 1994:130–135.

———, L.S. Kaufman, C.A. Chapman, and F.E. McKenzie. 1995. Hypoxia tolerance in twelve species of East African cichlids: Potential for low oxygen refugia in Lake Victoria. Conservation Biology 9(5):1274–1288.

Courtenay, W.R., Jr. 1993. Biological pollution through fish introductions. Pp. 35–61. *In*: McKnight, B.N. (ed.). Biological Pollution: The Control and Impact of Invasive Exotic Species. Indiana Academy of Science, Indianapolis, Indiana.

———, D.P. Jennings, and J.D. Williams. 1991. Appendix 2. Exotic fishes of the United States and Canada. Pp. 97–110. In: Robins, C.R., R. M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. Common and scientific names of fishes from the United States and Canada, 5th edition. American Fisheries Society Special Publication 20.

——— and J.D. Williams. 1992. Dispersal of exotic species for aquaculture sources, with emphasis on freshwater fishes. Pp. 49–81. In: Rosenfield, A. and R. Mann (eds.). Dispersal of Living Organisms into Aquatic Ecosystems. Maryland Sea Grant Program, College Park, Maryland.

———, D.A. Hensley, J.N. Taylor, and J.A. McCann. 1986. Distribution of exotic fishes in North America. Pp. 675–698. In: Hocutt, C.H. and E.O. Wiley, (eds.). The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, New York, New York.

——— and R.C. Robins. 1973. Exotic aquatic organisms in Florida with emphasis on fishes: a review and recommendations. Trans. Am. Fish Soc. 102:1–12.

———, H.F. Sahlman, W.W. Miley, and D.J. Herrema. 1974. Exotic fishes in fresh and brackish waters of Florida. Biol. Conserv. 6:291–302.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. J. Fish. Res. Board Can. 32:2295–2332.

Dial, R.S. and S.C. Wainright. 1983. New distributional records for non-native fishes in Florida. Florida Scient. 46:1–8.

Galis, F. and C.D.N. Barel. 1980. Comparative functional morphology of the gills of African lacustrine Cichlidae (Pisces, Teleostei): An ecomorphological approach. Neth. J. of Zool. 30:392–430.

——— and H. Smit. 1979. Hypoxia tolerance of two closely related *Haplochromis* species: *Haplochromis elegans*, Trewavas, 1933 and *H. angustrifrons* Boulenger 1914. Comp. Bioch. Physiol. 64A:137–139.

GEE, J.H. AND P.A. GEE. 1991. Reactions of gobioid fishes to hypoxia: Buoyancy control and aquatic surface respiration. Copeia 1:17–28.

———, R.F. TALLMAN, AND H.J. SMART. 1978. Reactions of some great plain fishes to progressive hypoxia. Can. J. Zool. 56:1962–1966.

HLOHOWSKYJ, I. AND T.E WISSING. 1987. Seasonal changes in low oxygen tolerance of fantail, *Etheostoma flabellare*, rainbow, *E. caeruleum*, and greenside, *E. blennioides*, darters. Env. Biol. Fish. 18:277–283.

HOGG, R.C. 1976. Established exotic cichlid fishes in Dade County, Florida. Biol. Sci. 39:97–103.

HOOGERHOUD, R.J.C., F. WITTE, AND C.D.N. BAREL. 1983. The ecological differentiation of two closely resembling *Haplochromis* species from Lake Victoria (*H. iris* and *H. hiatus*; Pisces, Cichlidae). Neth. J. Zool. 33:283–305.

HUGHES, G.M. 1980. Ultrastructure and morphometry of the gills of *Latimeria chalumnae*, and a comparison with the gills of associated fishes. Proc. R. Soc. Lond. B208:309–328.

———. 1984. Measurement of gill area in fishes: practices and problems. J. Mar. Biol. Ass. U.K. 64:637–655.

JENNINGS, D.P. 1986. Characterization of a localized Jack Dempsey, *Cichlasoma octofasciatum*, population in Alachua County, Florida. Florida Scient. 49:255–259.

KRAMER, D.L. 1983. The evolutionary ecology of respiratory mode in fishes: an analysis based on the costs of breathing. Env. Biol. Fish. 9:145–158.

———, D. MANLEY, AND R. BOURGEOIS. 1983. The effect of respiratory mode and oxygen concentration on the risk of aerial predation in fishes. Can. J. Zool. 61:653–665.

——— AND M. MCCLURE. 1982. Aquatic surface respiration, a widespread adaptation to hypoxia in tropical freshwater fishes. Env. Biol. Fish. 7:47–55.

KUSHLAN, J.A. 1979. Temperature and oxygen in an Everglades alligator pond. Hydrobiologia 67:267–271.

———. 1980. Population fluctuations in Everglades Fishes. Copeia 1980:870–874.

——— AND T.E. LODGE. 1974. Ecological and distributional notes on the freshwater fish of southern Florida. Florida Scient. 37:110–128.

LEWIS, W.M., JR. 1970. Morphological adaptations of cyprinodontoids for inhabiting oxygen deficient waters. Copeia 1970:319–326.

LIEM, K.F. 1980. Air ventilation in advanced teleosts: biomechanical and evolutionary aspects. Pp. 57–91. *In*: ALI, M.A. (ed.). Environmental Physiology of Fishes, Plenum Press, New York.

MILLER, R.R. 1966. Geographical distribution of Central American freshwater fishes. Copeia 1966:773–802.

MUIR, B.S. AND G.M. HUGHES. 1969. Gill dimensions for three species of tunny. J. Exp. Biol. 51:271–285.

NICO, L.G. 1995. National Biological Service, Gainesville, Florida, Pers. Commun.

OLOWO, J.P. AND L.J. CHAPMAN. 1996. Papyrus swamps and variation in the respiratory behaviour of the African fish *Barbus neumayeri*. Afr. J. Ecol. 34:211–222.

PALZENBERGER, M. AND H. POHLA. 1992. Gill surface area of water-breathing freshwater fish. Rev. Fish Biol. Fisheries 2:187–216.

ROBERTS, T.R. 1975. Geographical distribution of African freshwater fishes. Zool. J. Linn. Soc. 57:249–319.

SAINT-PAUL, U. 1984. Physiological adaptation to hypoxia of a neotropical characoid fish *Colossoma macropomum*, Serralsalmidae. Env. Biol. Fish. 11:53–62.

——— AND B.M. SOARES. 1987. Diurnal distribution and behavioral responses of fishes to extreme hypoxia in an Amazon floodplain lake. Env. Biol. Fish. 20:91–104.

SHAFLAND, P.L. AND J.M. PESTRAK. 1982. Lower lethal temperatures for fourteen non-native fishes in Florida. Env. Biol. Fish. 7:149–156.

ULTSCH, G.R., H. BOSCHUNG, AND M.J. ROSS. 1978. Metabolism, critical oxygen tension, and habitat selection in darters (*Etheostoma*). Ecology 59:99–107.

VERHEYEN, E., R. BLUSE, AND W. DECLEIR. 1994. Metabolic rate, hypoxia tolerance and aquatic surface respiration of some lacustrine and riverine African cichlid fishes (Pisces: Cichlidae). Comp. Biochem. Physiol. 107A:403–411.

WELCOMME, R.L. 1984. International transfers of inland fish species. Pp. 22–40. In: Courtenay, W.R. and J.R. Stauffer (eds.). Distribution, Biology, and Management of Exotic Fishes. John Hopkins University Press, Baltimore.

WINBERG, G.G. 1961. New information on metabolic rate in fishes. (Original in Russian). Translation Series No. 362, Fish. R. Board Can., Nanaimo, B.C. 201 pp.

WINEMILLER, K.O. 1989. Development of dermal lip protuberances for aquatic surface respiration in South American characid fishes. Copeia 1989:382–390.

WOODRUFF, A. 1983. Florida springs chemical classification and aquatic biological communities. M.Sc. Thesis, University of Florida, 116 pp.

YEAGER, D.P. AND G.R. ULTSCH. 1989. Physiological regulation and confirmation: A BASIC program for the determination of critical points. Physiol. Zool. 62:888–907.

Florida Scient. 60(1): 40–52. 1997
Accepted: July 30, 1996

AN INTRODUCTION TO THE TIDES OF FLORIDA BAY

NED P. SMITH

Harbor Branch Oceanographic Institution, 5600 U.S. Highway 1 North,
Fort Pierce, Florida 34946

ABSTRACT: *Water level records from 37 locations in Florida Bay are used to quantify semidiurnal, diurnal, fortnightly, monthly, semiannual and annual tidal constituents. Semidiurnal and diurnal waves enter primarily from the Gulf side of the bay, but also through tidal channels that connect Florida Bay with the Atlantic Ocean.* M_2 *amplitudes in the northwest corner of the bay are 35 cm; amplitudes in tidal channels along the southeast side of the bay are 15–20 cm.* S_2 *amplitudes decrease along the western boundary of the bay from 11 cm in the northwest corner to 2 cm at the southern end. Highest* S_2 *amplitudes in tidal channels are 4–6 cm.* K_l *and* O_l *constituents have highest amplitudes of 15 and 12 cm in the northwest corner of the bay. Semidiurnal and diurnal tidal waves converging toward the interior of the bay are heavily damped, and amplitudes are less than 1 cm in the northcentral and northeast parts of the bay. Long-period tides are damped less. Amplitudes of the fortnightly and monthly constituents are 1–3 cm at all stations. The amplitude of the annual tidal constituent is 8–10 cm throughout Florida Bay. Nontidal forcing introduces considerable station-to-station, and year-to-year variability in the phase angles of the semiannual and annual constituents. Semiannual constituent amplitudes are 3–5 cm and act to delay annual maximum water levels to late September.*

FLORIDA Bay lies directly south of Everglades National Park, at the southern end of the Florida peninsula. The bay is bounded on the east and south by the Florida Keys. Numerous tidal channels between keys exchange water between Florida Bay and continental shelf waters on the Atlantic side of the keys. The western boundary of Florida Bay cannot be defined by bottom topography, and the bay connects directly with the inner shelf of the Gulf of Mexico. Taking the 81°05′W meridian as the boundary, the surface area of Florida Bay is approximately 2,140 km^2. Water depth along this north-south line averages about 3 m; within the bay, water depth is characteristically 0.5 to 1.0 m. Mud banks and mangrove islands define a series of distinct basins that are connected by channels (Fourqurean et al., 1993).

The tides of Florida Bay represent the interaction of tidal waves in the eastern Gulf of Mexico and southwestern North Atlantic Ocean. Atlantic tides are primarily semidiurnal (Defant, 1958). Tides in the eastern Gulf are mixed semidiurnal (Zetler and Hansen, 1970). The earliest studies of tidal conditions in the Gulf of Mexico (Marmer, 1954; Zetler and Hansen, 1970) included harmonic constants from Key West, the Dry Torgugas and the southwest coast of the Florida peninsula, but no information was available from Florida Bay. Tidal conditions in Florida Bay were characterized in a qualitative way by Jones and co-workers (1973), who stated that tidal patterns at any given location can be extremely complex. Holmquist and co--workers (1989) recorded water levels at six sites on shallow mud banks and described tidal and seasonal water level ranges in the interior of the bay and around the fringe. Water level records were not analyzed for tidal constituents. A recent study by Wang and co-workers (1994) quantified amplitudes and phase angles of the principal tidal constituents at two stations. Results showed a west-to-east damping of tidal amplitudes, although spatial patterns could not be defined to describe the interaction of Gulf and Atlantic tidal waves.

The importance of tidal processes in Florida Bay is twofold. Tides provide a mechanism for exchanging water between the bay and the adjacent continental shelf on both the Atlantic and Gulf sides of the bay. Fourqurean and co-workers (1993) noted the importance of tidal exchanges for transporting phosphorus into the bay, as well as for reducing hypersaline conditions in the interior. The study by Wang and co-workers (1994) introduced the possibility that frictionally damped tidal waves entering Florida Bay from the Gulf of Mexico set up mean water levels within the bay and thus force an outflow of water through tidal channels along the southeast fringe of the bay. This would help explain why the observed net outflow is in a generally upwind direction (Smith, 1994). Residual transport induced by a tidal pumping mechanism is inversely related to water depth (van de Kreeke and Chiu, 1981).

The rise and fall of the tide is important also because it changes the depth significantly relative to the mean. Florida Bay is a macrophyte-dominated system, with approximately half of the bay's productivity occurring over the shallow mudbanks (Zieman et al., 1989). In view of the high turbidity of the water, even relatively small changes in water depth can have a profound effect on the amount of light available to support seagrass growth. In western parts of the bay, the semidiurnal tidal range can change the water depth by ±50 cm.

The purpose of this paper is to provide a clearer picture of the spatial variability of the semidiurnal and diurnal tides in Florida Bay by incorporating water level data from several sources. This is especially important along the western fringe of the bay where gradients are strongest, and in the northcentral and northeast parts of the bay where amplitudes are less than 1 cm. A second purpose of the paper is to extend earlier work by describing the long-period fortnightly, monthly, semiannual and annual tidal constituents.

DATA—The data base assembled for this paper includes harmonic constants from 37 study sites, obtained from four sources. Harbor Branch water level studies contributed time series from 13 locations along or to the west of the Everglades National Park boundary, and in tidal channels along the southeast perimeter of the bay (Stations 1–13 in Figure 1). Except for a float-and-counterweight tide gauge on the bay side of Long Key (Station 9), the Harbor Branch

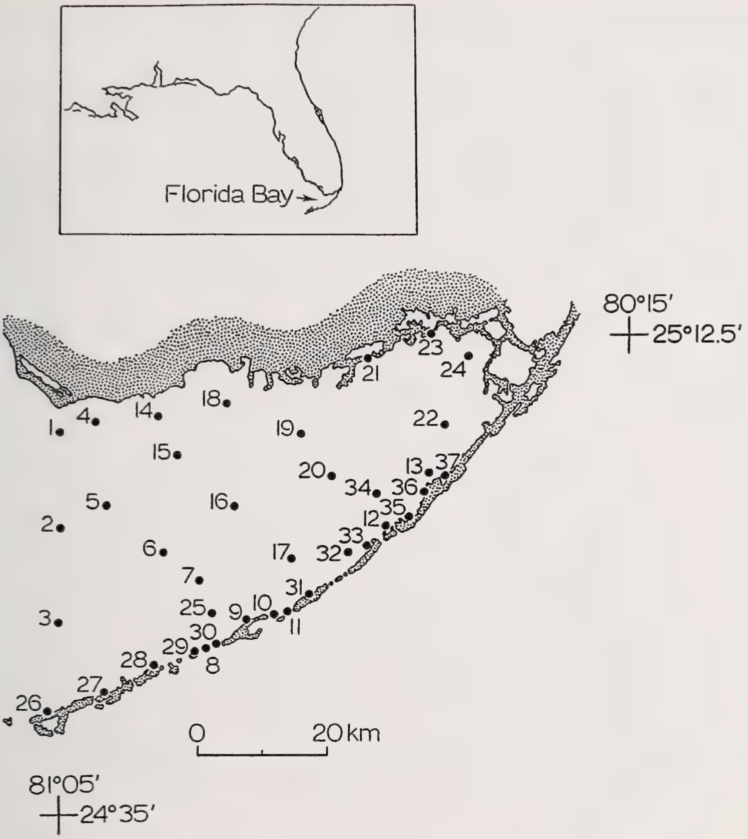


FIG. 1. Locations of the 37 study sites providing water level data from Florida Bay.

data are in the form of bottom pressure records. Pressure fluctuations have been converted to water level variations assuming a constant density of 1.024 gm cm^{-3}. A one decibar change in bottom pressure corresponds closely to a one meter change in water level. Individual readings are accurate to ±0.005 decibar (±0.5 cm), according to instrument specifications.

National Park Service personnel at Everglades National Park have maintained water level recorders on platforms in protected waters of the interior of Florida Bay as part of their Marine Monitoring Network since 1989. Data from 11 sites were used in this study (Stations 14–24). Water levels were tracked with a float-and-counterweight system, and the accuracy of the readings is ±0.3 cm.

Bottom pressure records from a National Data Buoy Center C-MAN weather station added data from Station 25 in the southern part of the bay. Finally, the National Ocean Service assembled water level records from throughout the Florida Keys south of Key Biscayne as part of their Marine Boundary and Coastal Mapping Program in the early 1970s (Martin, 1995). Harmonic constants of semidiurnal and diurnal constituents from 12 stations located along tidal channels, or on the Florida Bay side of the Keys were used in this study (Stations 26–37). Accuracy of the hourly observations is within ±0.3 cm.

The harmonic constants used to describe tidal conditions in Florida Bay include amplitudes, in cm, and local phase angles, in degrees. Local phase angles represent the interval, expressed in degrees, between the high water phase of an equilibrium tidal constituent at 75°

west longitude and the following high water of the same constituent in the tide observed at the study site (Schureman, 1958).

METHODS—Harmonic constants were quantified by one of two computer programs, depending on the length of the record. When the time series was shorter than a full year, a series of 29-day analyses (Dennis and Long, 1971) provided several amplitude and phase angle pairs for 24 diurnal, semidiurnal and shorter period tidal constituents. All harmonic constants for each of the principal tidal constituents were then vector averaged (Haurwitz and Cowley, 1975) to provide values more representative of the entire time series. Harmonic constants can be thought of as vectors, with the amplitude and local phase angle representing the magnitude and direction, respectively. Decomposing vectors into sine and cosine components, one can calculate the mean, as well as various measures of scatter about the mean. Comparison of the magnitude of the vector average with the probable error, for example, provides information on the statistical significance of the tidal constituent in question (Bartels, 1932).

When time series included a full year, a least squares analysis of the entire time series (Schureman, 1958) provided information on the fortnightly, monthly, semiannual and annual constituents, as well as on diurnal and semidiurnal constituents. The same computer program was used with a one-year record of surface pressure from Station 25 to investigate the effects that atmospheric tides might have on bottom pressure records obtained from Florida Bay.

The movement of individual tidal constituents through Florida Bay is traced using co-amplitude and co-phase charts. Both co-amplitude and co-phase charts were constructed by interpolating linearly between adjacent stations. With the combined data base, 21 of the 37 stations are from the interior of the bay, and the isopleths are much less subjective than they would be if water level records were from only the land-based stations surrounding the basin. Isopleths of local phase angles provide information on the speed and direction of tidal wave propagation. For semidiurnal constituents, a 30° phase lead or lag corresponds closely to a one hour time lead or lag. For diurnal constituents, a 15° phase difference corresponds to a one-hour time difference. Isopleths of amplitude provide information on how tidal waves are damped as they move through the bay. Phase angles have not been extended into the northcentral and northeast parts of the bay, where amplitudes are less than 1 cm. The 1 cm isopleth is used as an arbitrary boundary to define tideless parts of the bay for a given constituent.

RESULTS—Harmonic analysis identified six principal semidiurnal and diurnal tidal constituents: M_2, S_2, N_2, K_1, O_1 and P_1. Because of the microtidal conditions in Florida Bay, principal tidal constituents are defined to be those with amplitudes greater than 1 cm. Four tidal constituents, excluding N_2 and P_1, were selected for constructing co-amplitude and co-phase charts. The N_2 constituent is significant in the northwest corner with an amplitude of 7 cm at Station 1; the P_1 constituent is small throughout the bay (Table 1).

The co-amplitude chart for the M_2 tidal constituent shows a relatively uniform west-to-east decrease of about 2.0 cm km^{-1}, as the M_2 constituent enters the bay from the Gulf of Mexico and is damped in the shallow water (Fig. 2). Isolated pockets of locally significant M_2 amplitude are found along the southeastern fringe of Florida Bay, where connecting channels permit tidal waves to enter from the continental shelf on the Atlantic side of the keys. M_2 amplitudes are less than 1 cm in a 370 km^2 area in the northcentral and northeast parts of the bay. This represents about 17% of the total surface area if the bay is bounded by the 81°05′W meridian.

The interaction of converging tidal waves results in a complex co-phase chart (Fig. 3). The west-to-east increase in phase angle shows that semidi-

TABLE 1. Harmonic constants of the principal tidal constituents from Florida Bay water level recorders. Station numbers correspond to numbers shown in Figure 1. Amplitudes (η) are in centimeters; local phase angles (κ) are in degrees. An * indicates that the water level record was too short to quantify the amplitude and phase angle.

				Constituent										
Station	Lat. (N)	Lon. (W)		M_2	S_2	N_2	K_1	O_1	P_1	Mf	Msf	Mm	Ssa	Sa
1 8105 N	25°05.0′	81°05.0′	η	39.5	11.1	7.0	14.6	11.7	4.9	*	*	*	*	*
			κ	034	056	022	317	313	317	*	*	*	*	*
2 8105C	24°57.5′	81°05.0′	η	36.3	7.4	6.5	17.3	12.2	*	*	*	*	*	*
			κ	038	043	030	311	317	*	*	*	*	*	*
3 8105S	24°50.0′	81°05.0′	η	23.4	6.8	3.9	12.0	10.2	4.0	*	*	*	*	*
			κ	050	077	033	332	326	332	*	*	*	*	*
4 Marker 5	25°05.8′	81°01.9′	η	36.9	11.0	7.1	18.7	12.5	6.2	*	*	*	*	*
			κ	050	075	042	325	320	325	*	*	*	*	*
5 Oxfoot Bank	24°59.2′	81°00.7′	η	37.3	9.7	5.7	15.8	11.4	5.2	*	*	*	*	*
			κ	072	093	055	338	329	338	*	*	*	*	*
6 Sprigger Bank	24°54.8′	80°56.3′	η	23.4	7.0	3.8	11.9	10.1	3.9	*	*	*	*	*
			κ	061	092	040	325	324	325	*	*	*	*	*
7 Arsenic Bank	24°52.3′	80°53.0′	η	6.6	1.3	0.9	7.3	6.6	2.4	*	*	*	*	*
			κ	059	064	067	331	331	331	*	*	*	*	*
8 Long Key Channel	24°47.9′	80°52.2′	η	16.2	4.2	3.6	5.5	5.1	1.8	*	*	*	*	*
			κ	240	268	220	288	282	288	*	*	*	*	*
9 Keys Marine Lab	24°49.6′	80°48.9′	η	4.6	0.8	1.4	4.7	5.3	1.2	1.3	2.6	0.3	*	*
			κ	258	224	229	323	313	334	340	325	275	*	*
10 Channel Five	24°50.2′	80°46.3′	η	18.8	5.5	4.2	5.9	4.9	1.9	*	*	*	*	*
			κ	239	271	217	262	273	262	*	*	*	*	*
11 Channel Two	24°50.6′	80°45.1′	η	16.9	4.8	4.0	6.5	5.1	2.1	*	*	*	*	*
			κ	240	269	219	260	278	260	*	*	*	*	*
12 Windley Key	24°58.1′	80°36.6′	η	7.1	2.1	1.4	2.8	2.9	0.9	*	*	*	*	*
			κ	304	307	288	352	320	352	*	*	*	*	*

TABLE 1. Continued.

Station	Lat. (N)	Lon. (W)		Constituent										
				M_2	S_2	N_2	K_1	O_1	P_1	Mf	Msf	Mm	Ssa	Sa
13 Tavernier Creek	25°01.1′	80°33.1′	η	1.1	1.4	0.2	1.6	0.3	0.5	*	*	*	*	*
			κ	318	302	322	325	039	325	*	*	*	*	*
14 Murray Key	25°06.3′	80°56.5′	η	29.1	7.9	5.0	8.6	10.0	2.9	*	*	*	*	*
			κ	091	123	085	356	341	356	*	*	*	*	*
15 Johnson Key	25°03.1′	80°54.2′	η	13.9	4.1	2.3	6.6	5.7	1.8	1.4	3.3	0.7	0.5	7.6
			κ	110	132	095	019	012	027	296	043	034	139	145
16 Little Rabbit Key	24°58.9′	80°49.6′	η	1.5	0.5	0.2	2.2	2.3	0.8	0.4	2.5	2.1	3.0	8.2
			κ	113	173	080	045	030	057	312	048	037	068	172
17 Peterson Key	24°55.1′	80°44.8′	η	6.8	1.3	1.4	2.0	2.6	0.5	0.7	2.3	1.4	4.7	8.8
			κ	299	326	283	329	327	335	311	060	044	059	173
18 Buoy Key	25°07.3′	80°50.0′	η	2.4	0.7	0.4	1.8	1.8	0.7	0.2	2.5	2.2	3.2	8.4
			κ	168	196	139	088	076	108	275	070	037	052	151
19 Whipray Basin	25°04.7′	80°43.7′	η	0.5	0.3	0.1	1.3	1.2	0.5	0.5	2.4	2.3	2.3	8.8
			κ	228	234	210	093	081	103	289	062	051	064	165
20 Bob Allen Key	25°01.6′	80°40.9′	η	4.2	0.9	0.8	1.3	1.6	0.2	0.5	1.9	2.4	2.9	7.5
			κ	313	334	288	348	341	346	319	059	045	056	172
21 Little Madeira Bay	25°10.1′	80°37.9′	η	0.5	0.4	0.2	0.1	0.3	0.1	0.4	1.8	2.1	2.7	8.8
			κ	033	030	019	076	052	266	025	090	058	066	163
22 Butternut Key	25°05.1′	80°31.1′	η	0.4	0.1	0.1	0.3	0.3	0.1	1.0	1.7	1.8	2.5	9.0
			κ	035	162	352	073	062	060	311	092	051	037	161
23 Trout Cove	25°12.7′	80°32.0′	η	0.4	0.4	0.1	0.2	0.2	0.0	0.8	2.1	1.5	1.7	11.3
			κ	052	059	029	026	045	355	337	105	061	022	161
24 Duck Key	25°01.8′	80°29.4′	η	0.3	0.2	0.1	0.4	0.2	0.1	0.7	0.7	1.5	*	*
			κ	008	082	051	032	009	268	107	161	123	*	*

TABLE 1. Continued.

				Constituent										
Station	Lat. (N)	Lon. (W)		M_2	S_2	N_2	K_1	O_1	P_1	Mf	Msf	Mm	Ssa	Sa
25 NDBO C-MAN Station	24°50.6′	80°51.7′	η	1.4	0.4	0.7	5.1	5.6	1.7	*	*	*	*	*
			κ	273	151	249	324	321	324	*	*	*	*	*
26 Vaca Key, North	24°42.7′	81°06.1′	η	7.0	1.9	0.8	7.4	7.4	*	*	*	*	*	*
			κ	027	071	354	320	312	*	*	*	*	*	*
27 Fat Deer Key	24°44.0′	81°01.0′	η	15.4	4.0	2.3	7.9	8.3	*	*	*	*	*	*
			κ	061	085	022	345	329	*	*	*	*	*	*
28 Grassy Key	24°46.3′	80°56.4′	η	11.3	3.4	1.8	7.6	7.7	*	*	*	*	*	*
			κ	064	105	053	338	328	*	*	*	*	*	*
29 Conch Key	24°47.5′	80°53.0′	η	14.6	4.1	3.3	4.9	5.4	*	*	*	*	*	*
			κ	238	254	207	274	269	*	*	*	*	*	*
30 Long Key	24°48.1′	80°51.0′	η	15.5	3.5	3.5	4.2	4.7	*	*	*	*	*	*
			κ	235	259	217	255	267	*	*	*	*	*	*
31 Lower Matecumbe Key	24°51.9′	80°43.0′	η	10.9	1.9	2.5	3.1	4.0	*	*	*	*	*	*
			κ	256	263	235	317	314	*	*	*	*	*	*
32 Shell Key	24°55.4′	80°40.3′	η	8.4	1.4	1.7	1.4	2.3	*	*	*	*	*	*
			κ	284	316	267	311	312	*	*	*	*	*	*
33 Upper Matecumbe	24°55.5′	80°37.9′	η	6.7	1.3	1.4	1.5	2.0	*	*	*	*	*	*
			κ	297	315	269	327	319	*	*	*	*	*	*
34 East Key	24°59.8′	80°36.5′	η	7.0	1.3	1.7	0.9	1.6	*	*	*	*	*	*
			κ	305	347	282	313	313	*	*	*	*	*	*
35 Cowpens Anchorage	24°57.9′	80°34.1′	η	7.6	1.4	1.1	1.6	1.7	*	*	*	*	*	*
			κ	311	334	295	318	323	*	*	*	*	*	*
36 Plantation Key	25°00.1′	80°32.5′	η	1.0	0.1	0.1	0.9	0.6	*	*	*	*	*	*
			κ	321	246	344	195	105	*	*	*	*	*	*
37 Tavernier	25°00.9′	80°30.9′	η	0.5	0.4	0.2	0.6	0.3	*	*	*	*	*	*
			κ	342	192	123	157	174	*	*	*	*	*	*

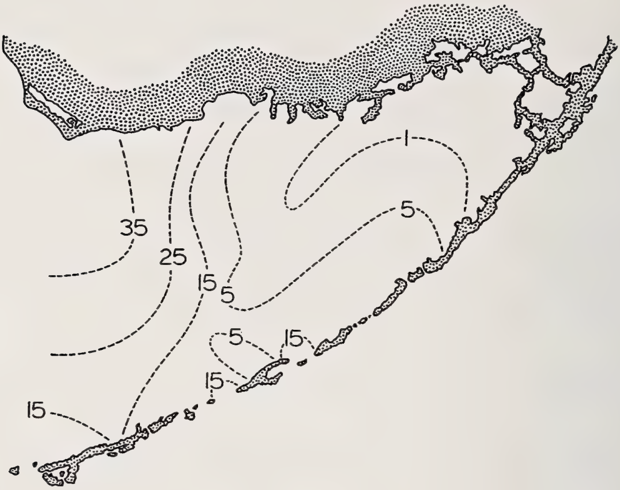


FIG. 2. Co-amplitude chart for the M_2 tidal constituent in Florida Bay. Isopleths are in centimeters.

urnal M_2 waves enter Florida Bay primarily from the Gulf of Mexico. Tidal waves entering the bay through tidal channels along the southeast fringe have a more local effect. In the southern part of the bay, isopleths of M_2 phase angles are tightly clustered, and a 180° phase difference occurs over a distance of less than 5 km just north of Long Key Channel (Station 8 in Fig. 1).

The spacing of the isopleths can be interpreted in terms of the speed of

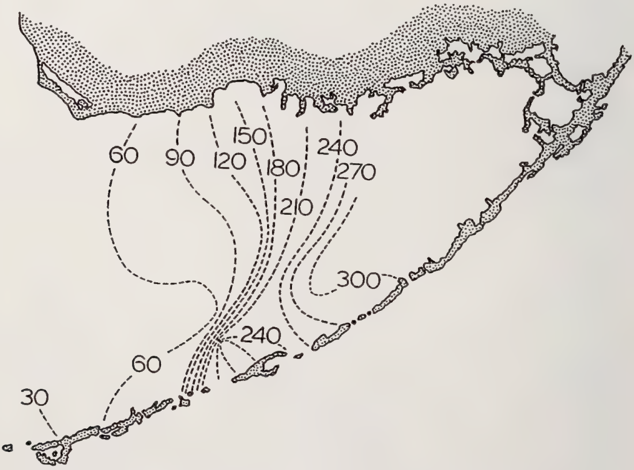


FIG. 3. Co-phase chart for the M_2 tidal constituent in Florida Bay. Local phase angles are in degrees.

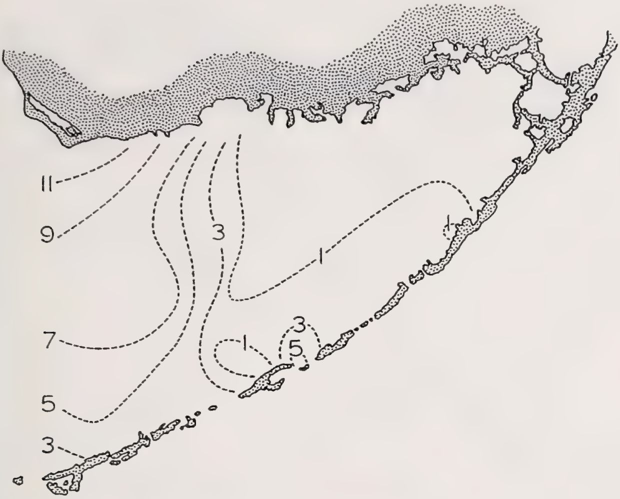


FIG. 4. Same as Figure 2, but for the S_2 constituent.

propagation of the tidal wave form. Tidal waves entering the bay from the Gulf of Mexico travel at speeds on the order of 5–10 km hr^{-1} in the northwestern part of the bay, then slow to 3–4 km hr^{-1} moving through the shallow water in the northcentral part of the bay (Fig. 3). In the southern part of the study area, tidal waves propagate from west to east at a speed of about 1 km hr^{-1}. This may represent the interaction of Gulf tidal waves with Atlantic tidal waves entering Florida Bay through tidal channels on either side of Long Key.

Highest amplitudes for the S_2 constituent are 11 cm in the northwest corner of the bay (Fig. 4). The west-to-east decrease is approximately 0.5 cm km^{-1}, and the 1 cm isopleth occurs just west of the northcentral part of the bay. The area within the 1 cm isopleth is approximately 830 km^2, which is 39% of the total surface area of Florida Bay. The north-to-south decrease in amplitude is 0.25 cm km^{-1}, and the S_2 amplitude at Station 26 (Fig. 1) is just under 2 cm. The S_2 co-phase chart (Fig. 5) shows waves entering from the Gulf and moving through the northern part of the bay at a speed of about 6 km h^{-1}. In the southern part of Florida Bay, the tightly compressed isopleths reveal a situation similar to that seen with the M_2 constituent. The 90° and 240° isopleths are only 5.2 km apart where Gulf and Atlantic S_2 tidal waves interact north of Long Key Channel.

The co-amplitude chart for the K_1 constituent (Fig. 6) contains maximum values of 15 cm in the northwestern corner of the bay; the 1 cm isopleth defines a 515 km^2 area in the northeast corner where the K_1 constituent is of negligible importance. Co-phase lines for the K_1 constituent (Fig. 7) indicate a convergent pattern with tidal waves moving into the northcentral part of the bay. The more closely spaced lines in the eastern part of the bay

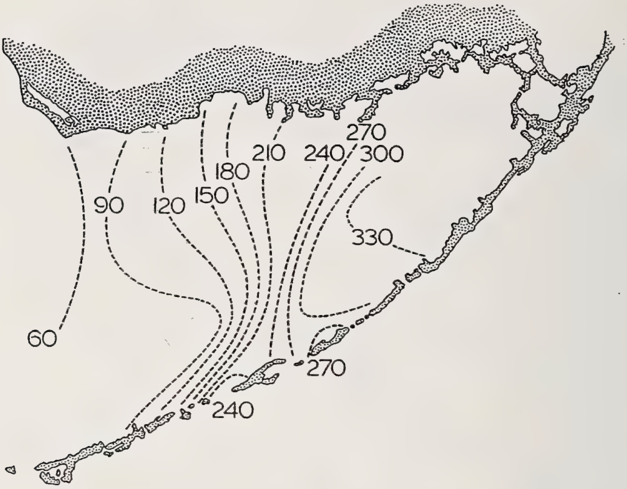


FIG. 5. Same as Figure 3, but for the S_2 constituent.

indicate that tidal waves move northward more slowly than they move eastward from the western side of the bay. The northward propagation speed is 1.1 km hr^{-1}, while the eastward propagation speed at the western end of the bay is 2.8 km hr^{-1}.

Highest O_1 amplitudes (Fig. 8) are near 12 cm in the northwest corner of the bay. Amplitudes decrease from west to east through the northcentral part of the bay at a rate of about 0.5 cm km^{-1}. Localized regions of relatively high amplitude are missing along the eastern and southeastern sides of the

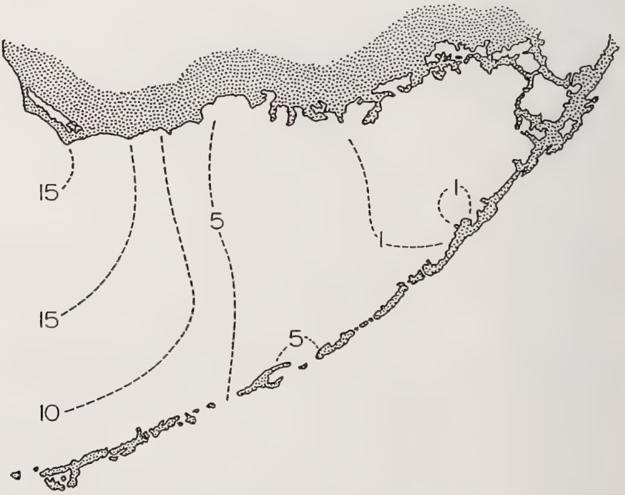


FIG. 6. Same as Figure 2, but for the K_1 constituent.

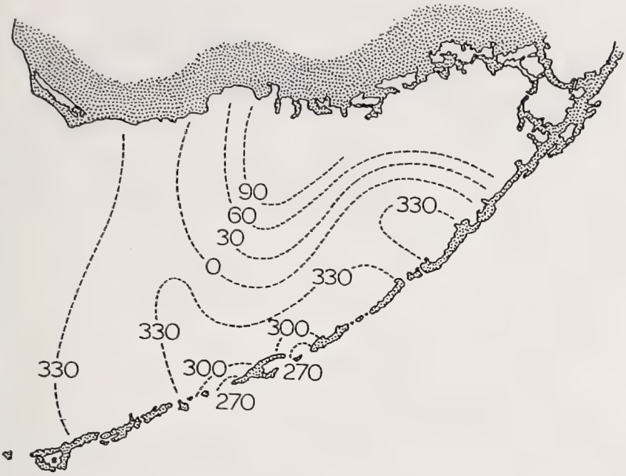


FIG. 7. Same as Figure 3, but for the K_1 constituent.

bay. The area with O_1 amplitudes less than 1 cm is 487 km^2, or about 23% of the total surface area of Florida Bay. The O_1 co-phase chart (Fig. 9) shows nearly uniform values along the western boundary. Tidal waves from both the Gulf of Mexico and from the Atlantic Ocean seem to be converging toward the northcentral part of the bay. O_1 propagation speeds are approximately 2–3 km h^{-1}.

The contaminating effect of atmospheric tides on bottom pressure records appears to be minimal for the semidiurnal and diurnal constituents. The principal atmospheric tidal constituent was S_2, but the amplitude was

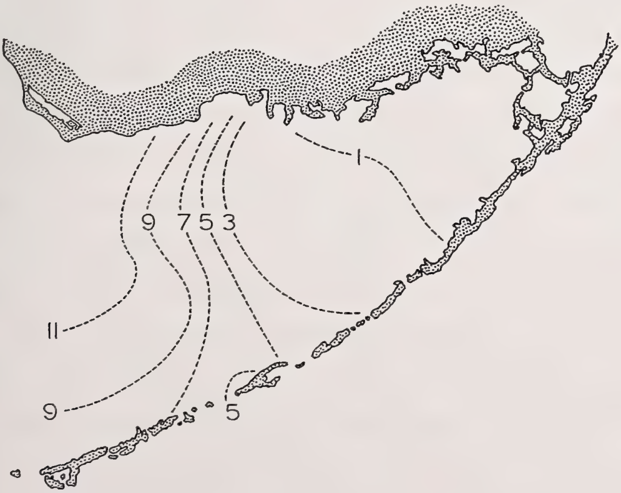


FIG. 8. Same as Figure 2, but for the O_1 constituent.

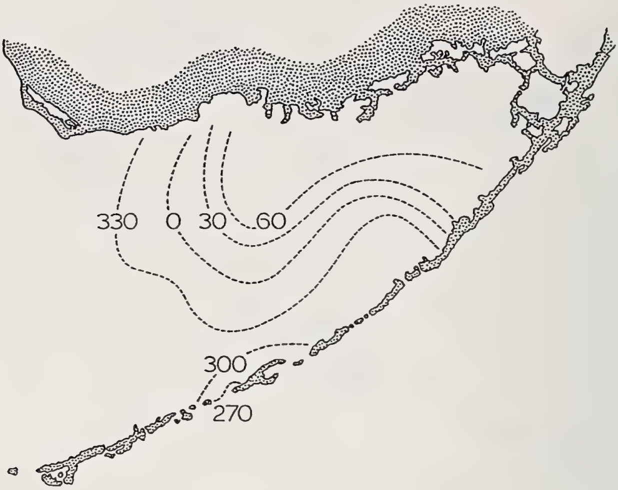


FIG. 9. Same as Figure 3, but for the O_1 constituent.

only 0.9 mb. The inverse barometer effect would translate this into a water level change of ±0.9 cm. Although this would be relatively large in the northeast corner of the bay, where all tidal constituent amplitudes are less than 1 cm, the perturbing effect of air pressure would be small throughout most of the study area. The amplitudes of the M_2, K_1 and O_1 constituents were 0.05, 0.02 and 0.03 mb, respectively.

Fourteen one-year time series from nine stations were used to quantify the amplitudes and local phase angles of the long-period tidal constituents. Harmonic constants were vector-averaged when a station had two or more one-year records. Amplitudes of the fortnightly and monthly tidal constituents are all within the range of 1–3 cm (Table 1). Msf and Mm amplitudes are slightly larger in the western part of the bay, but spatial gradients are weak. Lowest amplitudes in the northeast part of the bay are just under 2 cm. The Mf constituent is the smallest of the long-period constituents considered in this study. Amplitudes were less than 1.4 cm at all locations.

Figure 10 is a harmonic dial containing results of the 14 harmonic analyses that quantified the annual and semiannual constituents. Amplitudes of the Sa constituent are between 7 and 11 cm; phase angles are scattered between 140° and 210°. The vector average of the Sa harmonic constants assembled from Stations 14–24 has an amplitude of 8.6 cm and a phase angle of 163°, which produces a maximum water level in early September. The scatter for the Ssa constituent is similar to that for the Sa constituent, though amplitudes are smaller. The vector average of the Ssa constituent has an amplitude of 2.5 cm and a phase angle of 057°. The addition of the Ssa constituent to the Sa constituent raises the seasonal high water level to 9.8 cm above the annual mean, and it retards the occurrence of the year's highest water levels to the last week in September.

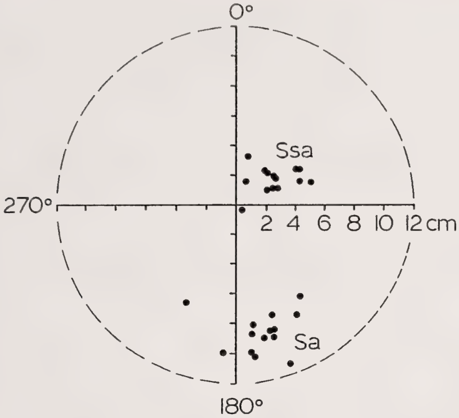


FIG. 10. Harmonic dial of Ssa and Sa constituent amplitudes and local phase angles from Florida Bay.

DISCUSSION—The picture that emerges from the integration of data from all stations within and bordering Florida Bay includes a rapid fringe-to-interior damping of semidiurnal and diurnal tidal constituents, and a large interior region dominated by long-period tidal constituents. Semidiurnal and diurnal tides are virtually absent in the northeast corner of the bay. Fortnightly and monthly tidal constituents contribute little to the total water level fluctuation at any location. Thus, the rise and fall in water level throughout much of the interior of the bay is restricted to nontidal fluctuations in response to meteorological forcing (outside the scope of this study), and the seasonal cycle, consisting of the combined effects of annual and semiannual constituents.

Given the data base available with the addition of stations 1–25 to the earlier NOS data, the harmonic constants of the principal semidiurnal and diurnal tidal constituents describe a spatially variable, but otherwise logical pattern. As a result of the interaction of Gulf and Atlantic tides, and because of the irregular bottom topography, harmonic constants do not vary uniformly across the bay. But the suggestion from earlier investigations that Florida Bay tides are extremely complex seems to be a reflection of the limited data base available at that time. In terms of spatial variability in the harmonic constants, Florida Bay is similar to other bodies of water that lie between seas with significantly different tidal conditions. Rocha and Clarke (1987) presented conceptually similar results from the Windward Islands, where Caribbean and Atlantic tides interact, and from the Strait of Gibraltar, where Atlantic and Mediterranean tides interact. Medeiros and Kjerfve (1988) found strong spatial gradients in the Strait of Magellan, where Atlantic tides interact with Pacific tides.

Nontidal forcing in two quite different forms influences the Sa and Ssa constituents in Florida Bay. Whitaker (1971) quantified the steric expansion and contraction of the water column over annual time scales using hydrographic data collected from throughout the Gulf of Mexico. Comparing Whitaker's results for the eastern Gulf of Mexico with the seasonal variation in water level for Florida Bay, as given by the sum of the Sa and Ssa constituents, it appears that steric effects explain approximately half of the mid-winter seasonal low water, and about one-third of the autumn high water level.

Alternately, atmospheric pressure may have a significant effect on the seasonal sea level cycle of Florida Bay. Mean monthly surface pressures from Miami and Key West (NOAA, 1985) can be averaged to represent Florida Bay. If one assumes that the water surface rises and falls 1 cm for every 1 mb change in surface pressure (Smith, 1979), then the inverse barometer effect explains approximately 25% of the fall maximum and mid-winter minimum water levels defined by the sum of the Sa and Ssa tidal constituents. One must invoke the inverse barometer effect with caution, however, because the deformation of sea level is in response to surface atmospheric pressure gradients, rather than the surface pressure at any given location. Without additional atmospheric pressure data from throughout the Gulf of Mexico, the importance of the inverse barometer effect cannot be quantified as a contribution to the seasonal cycle in Florida Bay. The available data, however, suggest that it may be a significant contributor.

The expanded data base used in this study is well suited for quantifying the longer period tidal constituents and for describing spatial variability in general terms. Additional data, however, will be useful for improving co-amplitude and co-phase charts in the southern part of the bay, especially near the major tidal channels. Spatial variability is greatest there as a result of interacting Gulf and Atlantic tidal waves. Nevertheless, incorporating the data collected over the past several years provides information needed to identify all the principal tidal constituents in Florida Bay, to define regions where these constituents are and are not important, and to reveal the spatial variability that results from the interaction of Gulf and Atlantic tidal waves.

ACKNOWLEDGMENTS—I am grateful to Douglas M. Martin, National Ocean Service, for providing the harmonic constants for Stations 26–37. J. Chris Humphrey, SEAKEYS Field Manager at the Keys Marine Laboratory on Long Key, provided the pressure data from the National Data Buoy Center C-MAN weather station near Long Key. Water level records from Stations 14–24 were obtained from DeWitt Smith at Everglades National Park, and were analyzed with the support of the National Park Service through Cooperative Agreement CA 5280-4-9022. Special thanks to Patrick Pitts for his initial screening, extensive editing and analysis of the NPS Marine Monitoring Network data base. Thanks also to Carolyn Petrie, who assisted in the editing and screening of the National Park Service data. Water level records from Stations 1–13 were obtained with financial support from the John D. and Catherine T. MacArthur Foundation through a grant to Florida Institute of Oceanography, from the Florida Department of Environmental Protection through Agreement 020, and by a grant from the National Oceanic and Atmospheric Administration's National Undersea Research Center at the University of North Carolina at Wilmington pursuant to NOAA award number NA36RU0060. Harbor Branch Oceanographic Institution Contribution Number 1160.

LITERATURE CITED

BARTELS, J. 1932. Statistical methods for research on diurnal variations. Terr. Magn. 37:291–302.

DEFANT, A. 1958. Ebb and flood: the tides of earth, air and water. University of Michigan Press, Ann Arbor, MI. 121 p.

DENNIS, R. AND E. LONG. 1971. A user's guide to a computer program for harmonic analysis of data and tidal frequencies. National Oceanic and Atmospheric Administration Technical Report 41, United States Department of Commerce, Rockville, MD.

FOURQUREAN, J.W., R.D. JONES, AND J.C. ZIEMAN. 1993. Processes influencing water column nutrient characteristics and phosphorus limitation of phytoplankton biomass in Florida Bay, Florida, U.S.A.: inferences from spatial distributions. Estuarine, Coast. Shelf Sci. 36:295–314.

HAURWITZ, B. AND A. COWLEY. 1975. The barometric tides at Zürich and on the summit of Säntis. Pure Appl. Geo. 113:355–364.

HOLMQUIST, J., G. POWELL, AND S. SOGARD. 1989. Sediment, water level and water temperature characteristics of Florida Bay's grass-covered mud banks. Bull. Mar. Sci. 44:348–364.

JONES, J.I., R.E. RING, M.O. RINKLE, AND R.E. SMITH. 1973. Physical oceanography of the northeast Gulf of Mexico and Florida continental shelf area. Pp. IIB1-IIB69. *In:* JONES, J.I., R.E. RING, M.O. RINKEL, AND R.E. SMITH (eds.) A Summary of Knowledge of the Eastern Gulf of Mexico, Florida Institute of Oceanography, St. Petersburg, FL.

MARMER, H.A. 1954. Tides and sea level in the Gulf of Mexico. Fishery Bull. 55:101–118.

MARTIN, D.M. 1995. NOAA/National Ocean Service, N/OES212, SSMC4, Sta. 7438, 1305 East-West Highway, Silver Spring, MD 20910–3233, Pers. Commun.

MEDIEROS, C. AND B.J. KJERFVE. 1988. Tidal characteristics of the Strait of Magellan. Continental Shelf Research 8:947–960.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. 1985. Local Climatological Data, Annual summary with comparative data, Miami and Key West FL. National Climatic Data Center, Asheville, NC.

ROCHA, C. AND A. CLARKE. 1987. Interaction of ocean tides through a narrow single strait and narrow multiple straits. J. Phys. Oceanogr. 17:2203–2218.

SCHUREMAN, P. 1958. Manual of harmonic analysis and prediction of tides. Special Publication Number 98, revised edition, United States Government Printing Office, Washington, D.C., 317 p.

SMITH, N. P. 1979. Meteorological forcing of coastal waters by the inverse barometer effect. Estuarine Coast. Mar. Sci. 8:149–156.

———. 1994. Long-term Gulf-to-Atlantic transport through tidal channels in the Florida Keys. Bull. Mar. Sci. 54:602–609.

VAN DE KREEKE, J. AND A. CHIU. 1981. Tide-induced residual flow in shallow bays. J. Hydr. Res. 19:231–249.

WANG, J.D., J. VAN DE KREEKE, N. KRISHNAN, AND D. SMITH. 1994. Wind and tide response in Florida Bay. Bull. Mar. Sci. 54:579–601.

WHITAKER, R.E. 1971. Seasonal variations of steric and recorded sea level of the Gulf of Mexico. Reference 71–14T, Texas A & M University Research Foundation, College Station, TX. 110 p.

ZETLER, B. AND D. HANSEN. 1970. Tides in the Gulf of Mexico—a review and a proposed program. Bull. Mar. Sci. 20:57–69.

ZIEMAN, J., J. FOURQUREAN, AND R. IVERSON. 1989. Distribution, abundance and productivity of seagrasses and macroalgae in Florida Bay. Bull. Mar. Sci. 44:292–311.

Florida Scient. 60(1): 53–67. 1997
Accepted: July 31, 1996.

INSTRUCTION TO AUTHORS

Individuals who wish to publish in the *Florida Scientist* must be active members in the Florida Academy of Sciences.

Submit a typewritten original and two copies of the text, illustrations, and tables to the editors. All typewritten material–including the abstract, literature citations, footnotes, tables, and figure legends–shall be double-spaced. Use one side of 8½ × 11 inch (21½ cm × 28 cm) good quality bond paper for the original; the copy may be xeroxed. Margins should be at least 3 cm all around. Number the pages through the Literature Cited section. Avoid footnotes and do not use mimeo, slick, erasable, or ruled paper. Use metric units for all measurements. *Papers in excess of 10 pages by an author in a single volume will result in page charges ($57 per page) for the excess pages.*

ADDRESS follows the author's name.

ABSTRACT–all manuscripts shall have a short, concise, single-paragraphed abstract. The abstract follows immediately the author's address.

ACKNOWLEDGMENTS are given in the body of the text preceding immediately the Literature Cited section.

LITERATURE CITED section follows the text. Double-space every line and follow the format in the current issue.

MANUSCRIPTS of 5 or less, double-spaced typewritten pages should conform to the short article protocol. See recent issue for proper format of both long and short articles.

TABLES shall be typed on separate sheets of paper, double-spaced throughout. Each table shall contain a short heading. Do not use vertical rulings. Maximum character width, including spaces, of tables is 98.0. This includes a minimum space of 5 characters between columns.

ILLUSTRATIONS–All drawings shall be done in good quality India ink, on good board or drafting paper. Letter by using a lettering guide or equivalent. Typewritten letters on illustrations are unacceptable. Drawings and photographs should be large enough to allow ⅓ to ½ reduction in size. Photographs shall be glossy prints of good contrast. Whenever possible, mount photographs in lots size.

The author's name and figure number should be penciled lightly on the back of each figure. Figure legends must be listed on a separate page and not on the drawing or photograph. The legend must be double spaced. Illustrations are charged to authors at $16.00 for halftones and $11.00 for line art.

We ask authors to prepare accepted manuscripts in personal computer formats. **Please do not submit a manuscript on disk.** Once reviewers have recommended a manuscript be accepted, you will be given directions for submitting the **final manuscript on disk.**

PROOF must be returned promptly. Notification of address change and proofreading are the author's responsibility. Alterations after the type has been set will be charged to the author.

REPRINTS may be ordered through the Business Manager from the printer on forms provided at the time that proofs are sent to authors for checking.

FLORIDA ACADEMY OF SCIENCES

INSTITUTIONAL MEMBERS FOR 1996

Archbold Biological Station
Brevard Community College, Palm Bay
The British Library, Boston Spa, Weatherby, UK
The British Library, RAS Washington DC
Professional Campus
Cleveland Public Library, Cleveland, OH
Environmental Protection Commission
of Hillsborough County, FL
Florida International University
Harbor Branch Oceanographic Institution, Inc.
Mote Marine Laboratory
Sea Camp Assocn., Inc. of Newfound Harbor Marine
Norris Library, Southern Illinois U, Carbondale, IL
St. Petersburg (FL) Junior College
St. Thomas University
St. Thomas University Library
Science Library, University of Chicago
South Hampton College, Long Island, NY
University of Miami

CORPORATE MEMBERS FOR 1996

Mote Marine Laboratory, Sarasota

Membership applications, subscriptions, renewals, and changes of address, should be addressed to the Executive Secretary, Florida Academy of Sciences, P.O. Box 033012, Indialantic, FL 32903-0012

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 University Blvd., Melbourne, FL 32901-6975 [(407) 768-8000, ext. 8196; e-mail rturner@fit.edu]

PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Special bargain: $500 for nearly complete sets. Prices quoted include domestic postage. Some issues may not be available. All are $20 per volume or $5 per issue, except for symposium issues.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES (1936–1944)
  Volumes 1–7
QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCE (1945–1972)
  Volumes 8–35
FLORIDA SCIENTIST (1973)
Florida's Estuaries—Management or Mismanagement?—Academy Symposium
  FLORIDA SCIENTIST 37(4)–$5.00
Land Spreading of Secondary Effluent—Academy Symposium
  FLORIDA SCIENTIST 38(4)—$5.00
Solar Energy—Academy Symposium
  FLORIDA SCIENTIST 39(3)—$5.00 (includes do-it-yourself instructions)
Anthropology—Academy Symposium
  FLORIDA SCIENTIST 43(3)—$7.50
Shark Biology—Academy Symposium
  FLORIDA SCIENTIST 45(1)—$8.00
Future of the Indian River System—Academy Symposium
  FLORIDA SCIENTIST 46(3/4)—$15.00
Second Indian River Research Symposium—Academy Symposium
  FLORIDA SCIENTIST 53(3)—$15.00

Please send payment with order. If required, an invoice will be sent on purchases over $20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.

Q
11
F6F63
NH

ISSN: 0098-4590

Florida Scientist

SMITHSONIAN
MAY 28 1997
LIBRARIES

Volume 60 Spring, 1997 Number 2

CONTENTS

Observations of Pineywoods Dropseed (*Sporobolus junceus*) Phenological Development Following Fire in a Sandhill Community .... Susan Littell Canfield and George W. Tanner 69
Stability of Silica Gel for Supported Chelators .... Charles D. Norris, Robert F. Benson, and Dean F. Martin 73
Maucha Diagrams and Chemical Analyses to Diagnose Changes in Lake Chemistry .... Andrew L. Hassell, Patricia M. Dooris, and Dean F. Martin 75
Heavy Metal Contamination in Sediment From Crane Creek, Florida .... Thomas K. Gregory and Matthew A. Charette 81
Observations of Insects Associated With an Infestation of Sand Pine (*Pinus clausa*) by the Aphid *Cinara pinivora* .... R. M. Clouse, B. Ferster, and M. A. Deyrup 89
A Preliminary Analysis of Neogene Depositional Environments in Broward County, Florida .... Charles W. Finkl, Jnr. and Luciana S. Esteves 94
The Impact of Lake Restoration on the Zooplankton Community in Banana Lake, Polk County, Florida .... John A. Osborne and Mary R. Egan 104
Predation on an Evening Bat (*Nycticeius* sp.) by Squirrel Monkeys (*Saimiri sciureus*) in South Florida .... Linda L. Taylor and Shawn M. Lehman 112
Effects of Fire on an Endangered Florida Plant, *Deeringothamnus rugelii* .... Joseph H. Helkowski and Eliane M. Norman 118
Production of Wheat and Triticale on Reclaimed Phosphatic Clay Settling Areas in Central Florida .... C. S. Gardner, G. M. Prine, R. D. Barnett, and E. C. French 124

FLORIDA SCIENTIST

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Copyright© by the Florida Academy of Sciences, Inc. 1997

Editor: Dr. Dean F. Martin Co-Editor: Mrs. Barbara B. Martin
Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, Florida 33620-5250
Phone: (813) 631-4121; e-mail: Martin@chuma.cas.usf.edu

Business Manager: Dr. Richard L. Turner
Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975
Phone: (407) 768-8000, ext. 8196; e-mail: rturner@fit.edu

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at $40.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

Officers for 1997–1998
FLORIDA ACADEMY OF SCIENCES
Founded 1936

President: Mr. Al Hall
City of Tallahassee
4335 Sherborne Road
Tallahassee, FL 32303

President-Elect: TBA

Secretary: Dr. Richard March
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416

Treasurer: Mrs. Georgina Wharton

Executive Secretary: Ms. Geralyn Heartz
Orlando Science Center
777 East Princeton St.
Orlando, FL 32803
407:896-7151, ext 2079; e-mail:
heartzfas@hotmail.com

Program Chairs: Dr. George M. Dooris
and Dr. Patricia M. Dooris
Department of Science and Mathematics
St. Leo College
St. Leo, FL 33574

Published by The Florida Academy of Sciences, Inc.
Printing by Allen Press, Lawrence, Kansas

Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

DEAN F. MARTIN, *Editor* BARBARA B. MARTIN, *Co-Editor*

Volume 60 Spring, 1997 Number 2

Biological Sciences

OBSERVATIONS OF PINEYWOODS DROPSEED (*SPOROBOLUS JUNCEUS*) PHENOLOGICAL DEVELOPMENT FOLLOWING FIRE IN A SANDHILL COMMUNITY

SUSAN LITTELL CANFIELD(1) AND GEORGE W. TANNER(2)

(1)Department of Forestry, University of Florida, Gainesville, FL 32611
(2)Department of Wildlife Ecology and Conservation, University of Florida,
Gainesville, FL 32611

ABSTRACT: *The phenology of pineywoods dropseed (*Sporobolus junceus*) after late winter and spring fires was evaluated. No significant relationship was found between basal area of pineywoods dropseed plants and the number of inflorescences produced per plant following the February fire; a significant but weak relationship was found in the plants following the May fire. Average basal diameter of plants at the February burn site (116.43 cm2) was significantly smaller than at the May burn site (185.91 cm2), possibly due to previous prescribed burns at the latter site. Following the May burn, pineywoods dropseed plants produced inflorescences and mature seed within seven to nine weeks of the fire.*

LONGLEAF pine (*Pinus palustris*) sandhill ecosystems in Florida are characterized by sandy soils, frequent fires, open pinelands, and a carpet of wiregrass (*Aristida beyrichiana*) (Myers and Ewel, 1990). Other grasses frequently are found in association with wiregrass in the longleaf pine ecosystem, such as pineywoods dropseed (*Sporobolus junceus*) and Curtiss dropseed (*Sporobolus curtissii*). Mixtures of wiregrass and pineywoods dropseed are most common (Hall, 1989). Wiregrass and pineywoods dropseed are similar in appearance; however, the two species can be distinguished by their inflorescences. The inflorescence of pineywoods dropseed "has spreading branches with small, scattered spikelets;" the inflorescence of wiregrass "is a narrow, compact panicle," with a spikelet characterized by three awns (Hall, 1989).

Considering efforts to restore Florida's longleaf pine sandhill ecosystem, it is important to investigate pineywoods dropseed's potential as an important component of the understory plant community. It is the understory wiregrasses, pine straw, and, in the winter, turkey oak (*Quercus laevis*) leaves, that provide the fuel for frequent, low intensity fires that shape the ecosystem (Myers and Ewel, 1990). Very little is known about the ecology, reproductive biology, response to fire, or role of pineywoods dropseed in the longleaf pine-wiregrass ecosystem.

SITE DESCRIPTION—Two study sites were located on the Katherine Ordway Preserve-Swisher Memorial Sanctuary approximately 55 km west of Gainesville, Florida. The Ordway Preserve's uplands are dominated by the longleaf pine, turkey oak, and sandhill ecosystem; the soil types include Candler fine sand, Apopka sand, and Astula fine sand (Gates, 1986). The first study site burned relatively hot on 25 February 1991; it had not been burned for approximately 20 years. The second study site burned with low intensity on 11 May 1991; it had been burned in the winters in 1985 and 1988.

METHODS—The study sites were burned on 25 February 1991 and 11 May 1991. Seventy plants were marked at the February burn site and 99 plants were marked at the May burn site approximately two weeks following each burn. Basal area of each plant was calculated approximately two months following each fire. Since not all plants had circular bases, the base of each plant was represented by the best fitting geometric figure (square, rectangle, circle, or triangle) in order to calculate the area.

Phenological development of the plants at the May burn site was monitored carefully for seed maturation as indicated by the presence of hard caryopses in florets. The reproductive state of each plant was recorded on 22 June 1991, 7 July 1991, and 30 July 1991; inflorescences were harvested on these dates as seeds matured.

RESULTS AND DISCUSSION—No significant relationship was found between basal area and the number of inflorescences produced per plant for pineywoods dropseed following the February fire; a significant but weak relationship was found in the plants following the May fire. The number of inflorescences produced by a plant of a given basal area was quite variable. Plants from the February burn site with a surface area of approximately 50 cm^2 produced from three to 25 inflorescences, and plants from the May burn site with a basal area of approximately 135 cm2 produced from four to 56 inflorescences. The variation in the number of inflorescences produced by plants of a given basal area may be attributed to differences in degree of fire damage, genetics, microhabitats, or a combination of all three variables. A plant that produced more inflorescences than another plant of the same basal area might have suffered greater fire damage; plants recovering from fire damage often respond with increasing sexual production (Hall, 1983). Also, a plant that produced more inflorescences than another plant of the

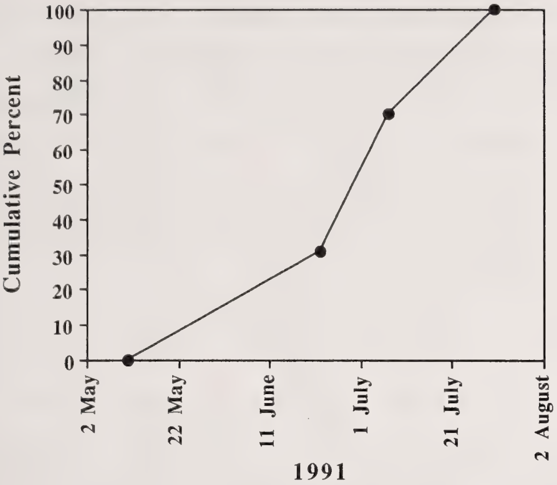


FIG. 1. Cumulative percent of pineywoods dropseed plants with mature seeds following a 11 May 1991 fire on the Ordway Preserve-Swisher Memorial, Putnam Co., FL.

same basal area might be genetically superior in terms of reproductive capability or might have more nutrients available in its microhabitat.

Average basal diameter of plants at the February burn site (116.43 cm^2) was significantly smaller than at the May burn site (185.91 cm^2). The two prescribed burns at the latter site in 1985 and 1988 potentially stimulated vegetative growth of existing plants.

Variation also occurred in the length of time between inflorescence production and seed maturation among the plants following the May burn. Between 11 May 1991 and 22 June 1991, the pineywoods dropseed plants

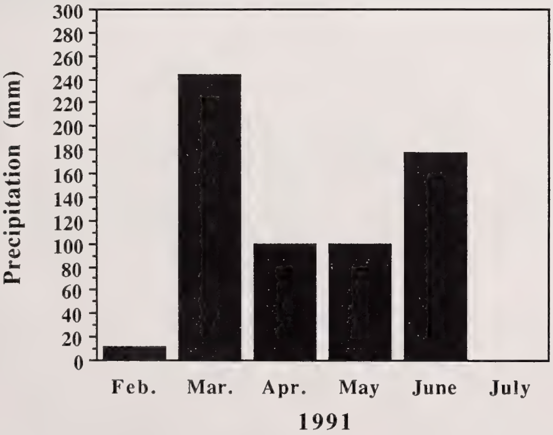


FIG. 2. Mean monthly precipitation for February through July1991 collected at Mill Creek on the Ordway Preserve-Swisher Memorial, Putnam Co., FL.

vegetatively regenerated and entered anthesis (Fig. 1). On 22 June 1991, 68 of 99 pineywoods dropseed plants were observed in early to mid-anthesis and 31 of 99 plants already had mature seeds as indicated by the presence of hard caryopses in florets. (The inflorescences of the 31 plants with mature seeds were harvested on 22 June 1991.) Many of the seeds of the 68 plants in anthesis on 22 June 1991 were mature by 7 July 1991. (The inflorescences of 38 of those 68 plants were harvested on 7 July 1991.) Mature seeds persisted on the inflorescences of 30 plants until 30 July 1991, at which time they were harvested.

Approximately seven weeks after the 11 May 1991 fire, pineywoods dropseed plants had returned to the typical vegetative condition and begun inflorescence production (Fig. 1). Approximately 31% of the plants had mature seeds within seven weeks of the fire and almost 70% of the plants had mature seeds within nine weeks of the fire. Variation in time of inflorescence production and seed maturation among pineywoods dropseed plants also may be attributed to differences in degree of fire damage, genetics, microhabitats, or a combination of all three variables. In general, the length of time between the May fire, inflorescence production, and seed maturation might have been influenced by precipitation following the fire. The May burn site received 10 cm of rain in May, and 17.7 cm in June (Fig. 2).

CONCLUSIONS—We observed pineywoods dropseed to flower and produce seed within seven to nine weeks following a spring fire. There was no relationship between plant basal area and inflorescence number; however, repeated burning may have increased basal areas of plants at the May burn site. Future research on seed germination following seasonal fire is needed if pineywoods dropseed is to be used in sandhill restoration procedures.

ACKNOWLEDGMENTS—We thank Dick Franz and Shirley West for their support and guidance with this work. This manuscript is Florida Agricultural Experiment Station Journal Series Number R-05610.

LITERATURE CITED

GATES, C. 1986. Masters Thesis. University of Florida, Gainesville, FL. 97 pp.

HALL, D. W. 1989. Is it wiregrass? Natural Areas Journal 9:1–4.

HALL, G. 1983. The role of fire in land use management. Department of Water Resources, St. Johns River WaterManagement District, Technical Publication SJ 83-4. 56 pp.

MYERS, R. L. AND J. J. EWEL (eds.). 1990. Ecosystems of Florida. University ofCentral Florida Press, Orlando, Florida. 765 pp.

Florida Scient. 60(2): 69–72. 1997
Accepted: August 20, 1996.

STABILITY OF SILICA GEL FOR SUPPORTED CHELATORS—

Charles D. Norris, Robert F. Benson, and Dean F. Martin, Institute for Environmental Studies, Department of Chemistry, University of South Florida, Tampa, FL 33620

ABSTRACT: *Silica gel used for support for supported chelators was tested in water and 42% phosphoric acid for stability. Sieve sizes were measured for control and for samples present in the solvents for one hour. The results indicate slight change in distribution for these conditions confirming the usefulness of this relatively cheap material for use as a support for chelating agents.*

PREVIOUS studies have indicated the usefulness of silica as a support for chelating agents (Benson and Martin, 1992). Specifically the method of attachment consists in filling silica pores with a hydrocarbon, e.g., hexane. Then a chelating agent with a long chain hydrocarbon is added. Presumably, the hydrocarbon chain will diffuse into the hexane-filled pores. When the hexane is evaporated, the hydrocarbon moiety develops hydrophobicity to the exposed hydroxyl groups on the surface of the silica pores. London forces favor a corkscrew configuration with about 2–3 turns for a chain of 12 carbons (cf. Noller, 1951). The spiral causes the hydrocarbon moiety to be wedged into the pores, leaving the polar chelating agent supported and available for reaction with metal ions.

Much information is available concerning silica and silicates (Eitel, 1964–76), but the present study is concerned with the effect of silica gel under specific conditions of application, potentially adverse conditions of exposure to water and 42% phosphoric acid.

MATERIALS AND METHODS—Silica gel (Grade 58, 3-12 mesh) was obtained from Fisher Scientific and used as received. A 50-g sample was placed in the 10 mesh sieve of a set of brass sieves. The sieve set was shaken together for 5 min, then two 20-g samples were removed from the sieve. One sample was washed in water; the second in reagent grade phosphoric acid (42.5%). Each sample was placed in a 250-mL beaker, and enough solvent was added to cover the sample. Both samples were placed in a New Brunswick Model G-2 gyrorotary shaker bath and shaken at 100 rpm for 30 min, then allowed to settle for 30 min. Solvent was decanted from the samples without loss. Solid samples were transferred to watch glasses and oven dried at 95° C overnight. Samples were allowed to cool to room temperature and were reweighed. Samples were washed with redistilled deionized water, shaken, dried, and sieved as before. The weight of each fraction, including the control was recorded.

RESULTS AND DISCUSSION—The fraction of silica gel as a function of sieve size is recorded (Table 1). The results indicate that there need be little concern that water or phosphoric acid will cause degradation of silica, at least as measured by change in sieve size. The sample treated with water was 96% of control, and the sample treated with 54% phosphoric acid was 90% of control.

TABLE 1. Percent mass distribution of silica sieved after washing in water or 1:1 phosphoric acid.

Mesh	Control[a]	Water[b]	1:1 H_3PO_4[b]
0–10	99.94	96.48	91.30
11–18	0.06	3.42	7.63
19–35	—	0.10	0.36
36–230	—	—	0.59
>230	—	—	0.04

[a] Not washed; [b] washing time 30 min (may not add up to 100%, owing to rounding errors).

The results reported here are for the worst-case scenario in the sense that silica whose pores were filled with hydrocarbon should be more resistant to degradation than plain silica. This was verified in two studies (Benson and Martin, 1992; Norris et al., 1997) of silica-supported chelating agents. Aqueous solutions of transition metals were treated with supported chelating agents, and the materials were stable over a range of pH (4–11). Results of the present study indicate that the systems might be applicable to metals in phosphoric acid.

ACKNOWLEDGMENTS—We are grateful to the reviewers for helpful comments, and we are grateful to Professor Leon Mandell for serving as Consulting Editor.

LITERATURE CITED

BENSON, R. F. AND D. F. MARTIN. 1992. Supported chelating agents. The corkscrew model. J. Envir. Sci. Health A27:2191–2197.

EITEL, W. 1964–1976. Silicate Science, vol. 1–7. Academic Press, New York, NY.

NORRIS, C. D., R. F. BENSON, AND D. F. MARTIN. 1997. Extraction of heavy metals by chelators attached to silica gel by a corkscrew mechanism. J. Environ. Sci. Health, submitted.

NOLLER, C. R. 1951. Chemistry of Organic Compounds. W. B. Sanders Company, Philadelphia, PA, p. 760.

Florida Scient. 60(2): 73–74. 1997
Accepted: August 21, 1996.

MAUCHA DIAGRAMS AND CHEMICAL ANALYSES TO DIAGNOSE CHANGES IN LAKE CHEMISTRY

ANDREW L. HASSELL(1), PATRICIA M. DOORIS(1, 2), AND
DEAN F. MARTIN(1)

(1)Institute for Environmental Studies, Department of Chemistry,
University of South Florida, Tampa, FL 33620-5250;
(2)Department of Environmental Science, Saint Leo College,
Saint Leo, FL 33574

ABSTRACT: *Computer-generated Maucha diagrams were used to demonstrate changes in the relative proportions of eight major ions in lakes located in northwest Hillsborough County, Florida. The change in chemistry of the lakes is ascribed to large-scale augmentation of lakes with water pumped from the Floridan aquifer. The ionic diagrams show notable increases in calcium and bicarbonate concentrations for artificially augmented lakes.*

FREQUENT episodes of abnormally low rainfall and increased groundwater withdrawals in Hillsborough County (Florida) in the past 25 years have resulted in depressed stages in many lakes (Dooris and Moresi, 1975; Stewart and Hughes, 1974). Since the early 1970s, lakefront property owners have attempted to maintain lake stages by artificially augmenting their lakes using water pumped from the Floridan Aquifer, the primary artesian aquifer in central Florida. Ground water is obtained from the two uppermost formations of the Floridan, the Tampa and Suwannee Limestones (Stewart and Hughes, 1974). In some lakes, large volumes of ground water have been added since the early 1970s.

With respect to certain chemical parameters, water from the Floridan Aquifer differs significantly from lake water in the same geographical area (Table 1). Changes in water chemistry could be anticipated in the augmented lakes, and the mixing of ground and surface water via augmentation presented an interesting study in water chemistry. Such changes in the chemistry of augmented lakes have been demonstrated in the past. It was shown that augmented lakes constituted a simple single-input system (Dooris, 1978). This system is simulated, over a short-time frame, by a container of lake water, a fraction of which has been replaced by ground water. In such containers, the concentrations of inorganic carbon are positively correlated with the volume percent of ground-water replacement of lake water ($r = 0.9996$; $p = 0.01$; Dooris, 1978), a likely consequence of the significantly greater concentration of bicarbonate ion in groundwater. Further, during earlier evaluations of the effects of augmenting lakes with deep-well water, it

TABLE 1. Comparison of selected chemical parameters for six lakes (1993) and ground water, Hillsborough County, Florida for calcium, magnesium, carbonate, bicarbonate ions, and sulfate (ppm).

Lake	Ca	Mg	CO_3	HCO_3	SO_4
Crystal	23.7–33.8	1.7–3.9	0.1–4.8	6.8–41.7	31.0–33.9
Cooper	14.5–19.4	2.3–5.8	0.0	9.2–10.2	42.0–51.5
Hobbs	12.9–17.5	2.3–5.5	N/A	0.5–1.0	51.3–54.6
Saddleback	27.5–37.6	0.8–1.74	0.4	63.3–83.8	7.9–8.3
Starvation	11.8–17.7	0.5–1.9	0.0–0.1	26.5–27.5	20.0–24.4
Strawberry	12.4–14.5	2.4–5.4	0.0	4.1–4.6	37.8–40.4
Floridan Aquifer*	63.0–110.0	6.2–6.6	0.0	160–350	59.0–63.0

* Data from Rosenau et al., 1977; Stewart and Hughes, 1974.

was shown that the practice led to significant increases in pH, hardness, and the concentration of inorganic carbon in receiving lakes (Martin et al., 1976). In addition, Dooris and Martin (1979), using ionic field diagrams first developed by Maucha (1932), showed that the pre-augmentation diagram for a lake matched the ionic diagram for a lake which had not been subjected to ground-water augmentation, while the post-augmentation diagram for the same lake was virtually identical to the ionic diagram for ground water from the Floridan aquifer. In addition, the ionic diagrams for non-augmented lakes showed that the relative proportions of the eight ionic constituents do not change significantly over the short term.

In artificially augmented lakes, large increases in the relative proportions of bicarbonate and calcium ions rose by the overwhelming dilution of original lake water that had comparatively low proportions of these two constituents. Specifically, the Maucha diagrams representing augmented lakes after augmentation had significantly greater areas associated with bicarbonate and calcium, and the later diagram was notably similar to the diagram for ground water (Dooris and Martin, 1979). A convenient program for calculating the Maucha or ionic-field diagrams has been developed (Hassell and Martin, 1995).

The majority of the previous work investigating the effect of groundwater augmentation on lakes was completed by the late 1970s, a time when augmentation had been used for less than ten years. This paper examines the chemical effects of over 20 years of augmentation of the same lakes investigated in the earlier studies and compares the recent chemical data with those from the earlier studies.

MATERIALS AND METHODS—*Site description*—Six lakes were selected for the study based upon their past history of groundwater augmentation and their geographical proximity to each other. Lakes Cooper, Hobbs, Saddleback, Starvation, Crystal, and Strawberry, were studied. All are located in northwest Hillsborough County (Florida) within Township 27, Range 18. They range in size from 18 acres (Crystal) to 82 acres (Cooper), and the drainage areas range from 0.7 to 2.0 mi^2. Each, except Lake Starvation, is connected to another lake. Of the six, four have a history of receiving groundwater from wells penetrating the Floridan Aquifer. Lakes Crystal, Saddleback, Starvation, and Strawberry were first augmented in the early 1970's, and augmen-

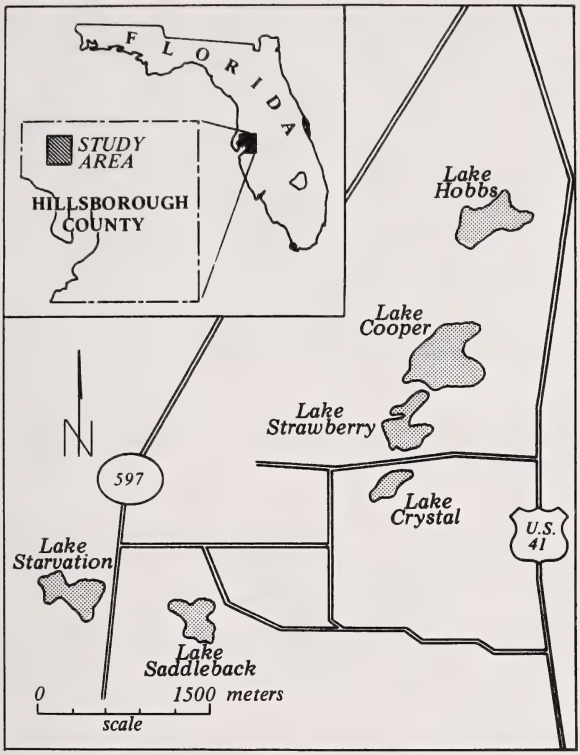


FIG. 1. Location of six study lakes in northwest Hillsborough County, Florida.

tation continues today in Lakes Crystal and Saddleback. Lake Starvation and Strawberry have not been augmented recently. The remaining two lakes, Hobbs and Cooper, have not been augmented. Therefore, the set of study lakes included two lakes which have been augmented with groundwater for over 20 years (Crystal and Saddleback), two lakes which had been augmented through the late 1970s (Starvation and Strawberry), and two lakes which have never been augmented (Hobbs and Cooper).

Sampling and analyses—Water samples were collected in January and September, 1993. Samples were collected in thoroughly washed, thrice-rinsed containers in the middle of each lake. The samples were cooled in a ice-water bath, transported to the laboratory, and stored at < 4°C prior to analysis. Chloride was determined by argentiometry with a potentiometric titration. Sulfate was determined by a turbidimetric method (APHA, 1989). Carbonate and bicarbonate were determined from an alkalinity titration (APHA, 1989). Sodium, potassium, calcium, and magnesium [with lanthanum(III) oxide ionization buffer] were determined by atomic absorption spectroscopy using a Perkin-Elmer model 460 (APHA, 1989). Pertinent data are summarized in Tables 1 and 2.

Maucha diagrams—Graphical methods were used to evaluate augmentation effects in the study lakes. Ionic field diagrams, first developed by Maucha (1932), described again by Hutchinson (1975), and by Broch and Yake (1969), were used to characterize the lake water chemistry. Using Q-Basic (Halvorson and Rygmyr, 1991), a program was written that permits input of basic concentrations and the size of the desired diagram, then by using a personal computer

TABLE 2. Comparison of selected chemical parameters for six lakes (1993) and ground water, Hillsborough County, Florida for sodium, chloride, and potassium ions (ppm); conductivity (μmho/cm²–25°C).

Lake	Na	Cl	K	Conductivity
Crystal	5.4–6.8	15.3–20.5	3.3–5.1	135–215
Cooper	6.6–6.8	24.9–32.5	7.9–8.8	205–230
Hobbs	7.2–8.8	21.2–24.3	6.9–7.9	205–215
Saddleback	1.7–2.9	10.8–11.9	1.5–3.3	155–200
Starvation	1.1–2.2	9.2–11.3	2.37	110–115
Strawberry	6.9–7.0	25.2–28.2	8.8	155–210
Floridan Aquifer*	77.0	6.0–12.0	0.6–0.7	393–459

* Data from Rosenau et al., 1977; Stewart and Hughes, 1974.

calculates the characteristics of the Maucha diagram for four cations and four anions (Hassell, 1994; Hassell and Martin, 1995).

RESULTS AND DISCUSSION—The Maucha diagrams for the six lakes and ground water (Figs. 2, 3) graphically depict the milliequivalents per liter (meq/l) for eight ions: K^+, Na^+, Ca^{++}, Mg^{++}, Cl^-, $SO_4^=$, HCO_3^-, and $CO_3^=$. The diagrams indicate that the meq/l of Ca^{++} and HCO_3^- are higher in Lakes

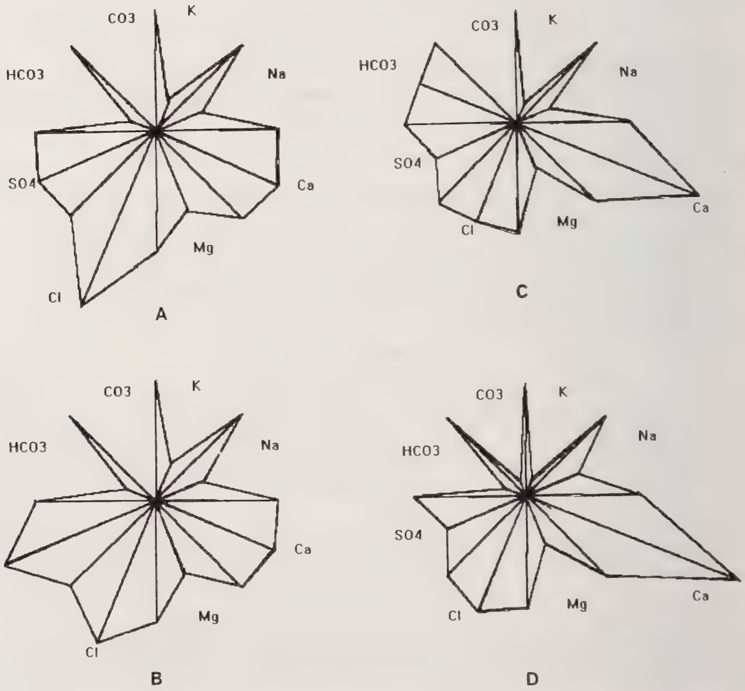


FIG. 2. Maucha diagram for (A) Lake Cooper, dry season, (B) Lake Cooper wet season, (C) Lake Crystal dry season, and (D) Lake Crystal wet season.

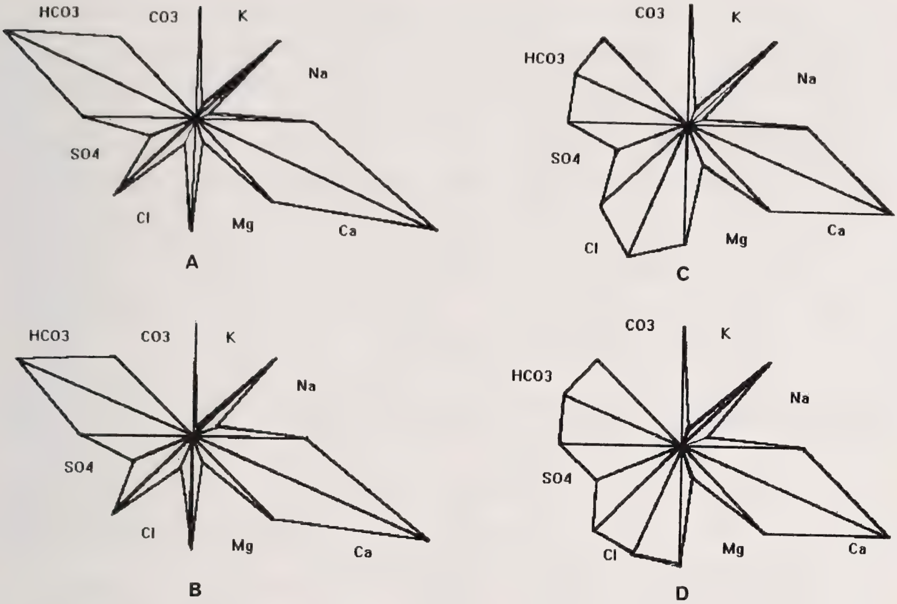


FIG. 3. Maucha diagram for (A) Lake Saddleback, dry season, (B) Lake Saddleback, wet season, (C) Lake Starvation, dry season, and (D) Lake Starvation, wet season.

Crystal, Saddleback, and groundwater than in the other lakes. Further, the diagrams for Lakes Hobbs and Cooper are virtually identical to each other as are those for Lake Saddleback and groundwater. The diagrams for Crystal and Saddleback both show high relative proportions of the Ca^{++} and HCO_3^-, but Saddleback has lower proportions for the other six ions than does Crystal. The diagram for Lake Strawberry resembles those for Lakes Hobbs and Cooper, suggesting that the cessation of augmentation results in a return to pre-augmentation conditions. This phenomenon is also seen in the diagrams for Lake Starvation for 1973 and 1993 in which the earlier diagram is virtually the same as the diagram for ground water, but the later diagram shows at least a partial return to pre-augmentation conditions.

The diagrams also indicate that several ions are not diagnostic of the groundwater augmentation: $CO_3^=$, $SO_4^=$, Na^+, and Mg^{++}. Lastly, the diagrams indicate that K^+, highest in Lakes Hobbs and Cooper, suggests the absence of augmentation.

While this study focused on discerning the effects of augmentation, the Maucha diagrams also can be used to demonstrate other differences and trends in chemical characteristics. For example, the diagrams show a greater fraction for chloride ion than was noted previously (Dooris and Martin, 1979), suggesting the possibility of salt-water intrusion. An earlier study emphasized the importance of intrusion indices, one of which is the Chloride Index, and the diagnostic utility for following the impact of salt-water intrusion along the west coast of Florida (Martin et al., 1991). The use of modified Maucha diagrams is a convenient method for following the response of inorganic ions in fresh water to outside perturbations potentially affecting water chemistry. In the particular case of augmented lakes, the diagrams also permit a determination of the restoration of typical surface water chemical characteristics after augmentation has ceased. The diagrams will, therefore, be useful in following the changes in water chemistry expected to accompany the growing practice of augmenting desiccated wetlands located in wellfields in west central Florida. The availability of a user-friendly computer program (Hassell, 1994) increases the ease of generation of these diagnostic diagrams, and should encourage their use.

ACKNOWLEDGMENTS—We are grateful for the helpful comments of the reviewers, and we appreciate the helpful comments of the Consulting Editor, Barbara B. Martin.

LITERATURE CITED

APHA. 1989. Standard Methods for the Examination of Water and Wastewater, 17th edition, American Public Health Association, Washington, D.C.

BROCH, E. S. AND W. YAKE. 1969. A modification of Maucha's ionic diagram to include ionic concentration. Limnol. Oceanog. 14:933–935.

DOORIS, P. M. 1978. *Hydrilla verticillata*: Chemical Factors in Lakes Affecting Growth. Ph.D. dissertation. Dept. of Biol., U. of So. Fla., Tampa, Florida, 177 pp.

——— AND D. F. MARTIN. 1979. Ground-water induced changes in lake chemistry. Ground Water 17:324–327.

——— AND R. J. MORESI. 1975. Evaluation of lake augmentation practices in northwest Hillsborough County, Florida. Tech. Report., S. W. Florida Water Management District, Brooksville, FL.

HALVORSON, M. AND D. RYGMYR. 1991. Running MS-DOS Basic. Microsoft Press. Redmond, WA.

HASSELL, A. L. 1994. A chemical and biochemical characterization of Lakes Cooper, Strawberry, Crystal, Hobbs, Starvation, and Saddleback in Hillsborough County (Florida), M.S. thesis, Dept. of Chemistry, University of South Florida, Tampa, FL.

——— AND D. F. MARTIN. 1995. A computer generated (Q-BASIC) program to construct Maucha diagrams. Florida Scient. 58:300–312.

HUTCHINSON, G. E. 1975. A Treatise on Limnology. I. Geography, Physics, and Chemistry, John Wiley & Sons, Inc., New York, N.Y.

MARTIN, D. F., C. D. NORRIS, AND B. B. MARTIN. 1991. Intrusion indices—A measure of groundwater quality. J. Environ. Sci. Health A26:899–910.

———, D. VICTOR, AND P. M. DOORIS. 1976. Effects of artificially introduced ground water upon the chemical and biochemical characteristics of six Hillsborough County (Florida) lakes. Water Res. 10:65–69.

MAUCHA, R. 1932. Hydrochemisce Methoden in der Limnologie. Binningewasser 12:173 pp.

ROSENAU, J. C., G. L. FAULKNER, C. W. HENDRY, JR., AND R. W. HULL. 1977. Springs of Florida. Florida Dept. Of Environmental Protection (formerly Florida Dept. of Natural Resources), Bureau of Geology. Tallahassee, FL. 459 pp.

STEWART, J. AND G. HUGHES. 1974. Hydrologic consequences of using ground water to maintain lake levels affected by water wells near Tampa, Florida. Open-File Rept. 74006. USGS, Tallahassee, Florida.

Florida Scient. 60(2): 75–80. 1997
Accepted: August 21, 1996.

HEAVY METAL CONTAMINATION IN SEDIMENT FROM CRANE CREEK, FLORIDA

Thomas K. Gregory[1] and Matthew A. Charette[2]

Division of Marine and Environmental Systems Florida Institute of Technology,
Melbourne, FL 32901

Abstract: *Vertical profiles for concentrations of Ag, As, Cu, Hg, and Zn in two sediment cores from Crane Creek, Florida indicated that metals were present at 5 to more than 30 times natural levels. Comparison of sediment metal concentrations with values for sediment quality criteria predicted occasional adverse biological effects due to the presence of Ag, Cu and Zn, and frequent adverse biological effects due to Hg contamination. Sediment geochronologies determined by Cs-137 and excess Pb-210 suggest that Crane Creek has been stressed by elevated levels of heavy metals since the early 1950s.*

Since the age of industrialization, various coastal and estuarine environments have been contaminated by anthropogenic inputs of heavy metals (Goldberg et al., 1977). Elevated levels of heavy metals have been observed in such diverse locations as Japan (Nishimura and Kumagai, 1983), Greece (Papakostidis et al., 1975), Australia (Bloom and Ayling, 1977) and the Ivory Coast (Kouadio and Trefry, 1987). Heavy metals enter the environment from varied sources including industrial and mining effluents, combustion of fossil fuels, discharge of sewage and sludge, excess fertilizer and pesticide runoff, and diffuse urban runoff (Forstner and Wittman, 1979). Transport of heavy metals to coastal sediments is by rivers and streams, direct discharge and atmospheric fallout (Bruland et al., 1974).

Population growth along Florida's Indian River Lagoon (IRL) over the past thirty years has led to an increase in the accumulation of fine-grained, organic-rich sediment sometimes referred to as 'muck' (Trefry et al., 1990). This sediment provides an ideal surface for adsorption of heavy metals and studies in the IRL have identified metals in excess of natural levels (Trefry et al., 1992). One area impacted by heavy metal contamination is Crane Creek, one of many tributary creeks flowing into the Indian River Lagoon. Crane Creek flows through Melbourne, Florida and is a popular place for fishing, bird watching and manatee observation. Preservation of Crane Creek is therefore essential to the City of Melbourne, and identification of potential

---

[1] Present address: Marine and Environmental Studies, University of San Diego, 5998 Alcala Park, San Diego, CA 92110

[2] Present address: Graduate School of Oceanography, The University of Rhode Island, Narragansett, RI 02882

TABLE 1. Concentrations of trace metals in standard marine sediments BEST-1 (Hg) and BCSS prepared by the National Research Council of Canada (μg/g dry weight except for Fe).

Element	Certified Value	Values From This Study
Fe	3.29 ± 0.10%	1.79 ± 0.06%
Cu	18.5 ± 2.7	12.8 ± 0.05
Zn	119 ± 12	86.2 ± 0.1
As	11.1 ± 1.4	8.78
Hg	0.092 ± 0.009	0.086

problems such as heavy metal contamination is paramount to maintaining the health of Crane Creek.

STUDY AREA—Crane Creek is one of many creeks draining into the Indian River Lagoon (IRL), a bar built estuary extending approximately 250 km along the Atlantic coast of Florida. Crane Creek drains about 49 km^2 of suburban Melbourne, FL (Rao, 1987) and has a marina with gasoline and diesel service near the mouth. The Florida East Coast Railroad runs directly over Crane Creek, as does highway U.S. 1. Two sample sites were chosen in Crane Creek, one adjacent to the Florida Institute of Technology anchorage (East Crane Creek, ECC) and one just west of the railroad trestle (West Crane Creek, WCC).

METHODS—Sediment cores were collected from Crane Creek on September 16, 1993 from a small skiff. Coring was performed by hand using cellulose-acetate-butyrate tubing, ~ 7 cm in diameter. The tubing was inserted vertically into the mud taking care not to disturb the integrity of sediment column, capped, extracted and sealed for transport to the lab. Cores contained black, organic-rich sediment and were 65 cm (ECC) and 45 cm (WCC) in length.

Upon returning to the laboratory, the cores were split longitudinally and subsectioned into 2 and 4 cm intervals and placed into acid-washed vials, then freeze dried. Wet sample was retained for Hg analysis to avoid loss during the freeze drying process. An acid leach was performed on approximately 2 g of the freeze dried sediment samples with 5 ml of concentrated HNO_3. After heating for about 60 minutes, the samples were filtered through Whatman #40 filter paper and diluted to 25 ml with distilled, deionized water and placed in acid washed vials. Concentrations of Cu, Fe, and Zn were determined using a Perkin-Elmer (P-E) model 4000 atomic absorption spectrophotometer (AAS) with an air-acetylene flame. Concentrations of As were determined using a P-E model 5100 PC AAS equipped with graphite furnace atomization, P-E model 5100 Zeeman background correction, and P-E model AS-60 autosampler. Instruments were set to manufacturer recommended adjustments for each element.

Mercury was extracted from approximately 2 g of wet sediment by heating the sediment with 5 ml concentrated HNO_3 in a water bath at 65°C for one hour. The leach was performed in acid-washed polypropylene centrifuge tubes. After cooling, the samples were centrifuged and the supernatant diluted to 20 ml with distilled, deionized water. The procedure follows that described in Trefry and co-workers (1992). Water content was determined on separate portions. Mercury was analyzed by cold vapor AAS using a Laboratory Data Control Mercury Monitor. Concentrations of Ag were determined using a P-E model 4000 flame AAS using the Hg digest samples. Background correction was used for this analysis.

Analytical accuracy was determined by analysis of Standard Reference Material (SRM) BEST-1 for Hg and SRM BCSS for all other elements (Table 1). Analytical precision for elements for which replicates were run was better than 17%. The HNO_3 acid leach performed obtained 54% to 79% of the metals present (except for Hg, for which almost all metal was obtained), as shown by SRM data. Contaminant metal present in sediment is adsorbed onto the surface of the sediment grains while naturally occurring metals are tied up in the crystalline structure of the aluminosilicate sediment. Thus, a leach which removes only the metal adsorbed onto the surface of the sediments, i.e. the anthropogenically introduced metals, may be a more useful means for assessing anthropogenic inputs (Kane et al., 1993).

Sediment geochronologies were determined on selected subsamples using a Princeton Gamma Tech Intrinsic germanium detector calibrated for determination of the radionuclide of interest. Pb-210 activity was determined at 46.5 keV, Pb-214 at 351.9 keV, and Cs-137 at 661.6 keV.

RESULTS AND DISCUSSION—Concentrations of Ag, As, Cu, Hg, Zn were normalized to Fe to aid in identifying metal contamination. Iron is associated with aluminosilicate minerals, and trace metal contaminants have a high affinity for these fine-grained sediments. Thus, comparisons of metal/Fe ratios provides a way to determine if the trace metals present are contaminants (Bruland et al., 1974; Trefry and Presley, 1976; Trefry and Kouadio, 1987). Sediments are considered contaminated with a trace metal if the metal/Fe ratio is higher than natural levels and exceeds the 95% prediction interval for the natural ratio. This approach has been used with Al by the State of Florida to determine metal contamination (Schropp et al., 1990). The Fe/Al ratio in sediments (e.g. Trefry et al., 1992) is quite good and thus Fe may be used as a proxy for Al. When sediments are leached, Fe must be used because very little Al goes into solution during a HNO_3 leach.

Simply identifying metal contamination does not, however, indicate adverse effects of elevated metal concentrations on biota. For this reason, guidelines are being developed by Long and co-workers (1994) to establish metal concentrations for which adverse biological effects may be observed. For each metal, Long and co-workers (1994) give two concentrations, an **E**ffects **R**ange-**L**ow (ERL) and an **E**ffects **R**ange-**M**edian (ERM). If a sample has a metal concentration between the ERL and ERM, biological effects due to that metal may be occasional while a metal concentration above the ERM may produce frequent adverse biological effects. In this study, we first identify metal contamination in sediment by metal/Fe ratios, then compare metal concentrations to values for ERL and ERM to consider possible biological effects due to the presence of elevated metal concentrations.

Downcore profiles for Zn and Cu were very similar for each core. Concentrations of Zn and Cu decreased with depth in the WCC core and both metal concentrations remained relatively consistent throughout the ECC core (Fig. 1a, Table 2). Sediment metal concentrations in both cores can be considered to be at contamination levels, as mean metal/Fe ratios exceed natural levels by 3 to 6.8 times (Table 3). Both Cu and Zn are present in both cores at levels above the ERL, except for the bottom of WCC for both metals and the middle of ECC for Zn (Fig. 2a). Based on concentrations of these two metals, Long and co-workers (1995) predict occasional biological effects.

Mercury and Ag concentrations determined from portions (top, middle, bottom) of the cores were as much as 40 times greater than natural levels (Table 2). In the WCC core, Hg levels generally decreased with depth, ap-

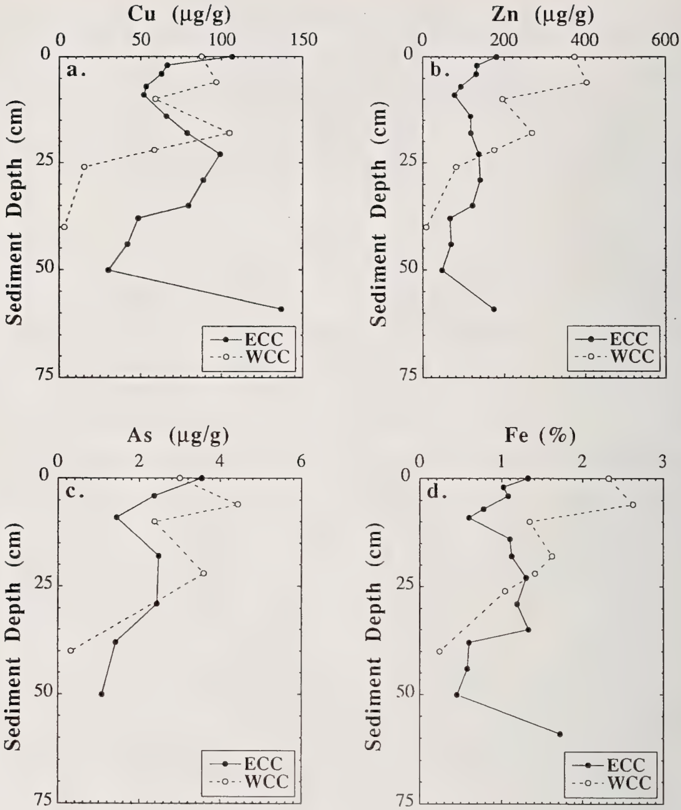


FIG. 1. Vertical profiles for (a) Cu, (b) Zn, (c) As, and (d) Fe in sediment cores at ECC and WCC.

proaching natural levels at the bottom. Silver followed a similar trend at this site. Mercury concentrations at the ECC core were high overall and increased with depth. At the same location, Ag was high throughout the core. Metal/Fe ratios also indicated contamination, as shown in Table 3, where Hg was as high as 92 times the natural ratio. Figure 2c shows Ag concentrations in both cores well above ERL values, except for the bottom of WCC; also shown are Hg concentrations above ERM values for several samples and above the ERL for others. Again, the bottom of WCC has concentrations of Hg below the ERL. Therefore, we predict occasional to frequent effects due to Hg and occasional effects due to Ag for most of both cores.

Tables 2 and 3 and Figure 1c show that As concentrations in the two cores ranged from 0.31 ppm to 4.4 ppm. Mean As/Fe ratios for the two cores suggest that As is present in the sediment of Crane Creek at about five times natural levels. While As/Fe ratios indicate contamination, none of the samples analyzed were above ERL values, indicating that As contam-

TABLE 2. Metal Concentrations (µg/g except Fe) found in sediment cores from Crane Creek including mean ± standard deviation, range and average crustal abundances (dry weights).

	Fe (%)	Cu	Zn	As	Hg	Ag
ECC (n = 14)				(n = 7)	(n = 3)	(n = 3)
Mean	1.01 ± 0.360	72.0 ± 29.0	115 ± 40.0	2.11 ± 0.850	0.85 ± 0.60	2.63 ± 1.70
Range	0.450–1.70	30.0–137	47.0–173	1.10–3.50	0.19–1.70	2.30–3.10
WCC (n = 7)				(n = 5)	(n = 3)	(n = 3)
Mean	1.51 ± 0.790	61.0 ± 39.0	215 ± 145	2.74 ± 1.60	0.70 ± 0.60	2.34 ± 1.70
Range	0.240–2.60	3.10–98.0	8.10–4.30	0.310 ± 4.40	0.07–1.3	0.400–3.40
Continental Crust	4.1	50	75	1.5	0.05	0.07

TABLE 3. Metal to iron ratios (× E-04) for Crane Creek sediment cores including mean ± standard deviation, range and average crustal ratios (dry weight).

	Cu/Fe	Zn/Fe	As/Fe	Hg/Fe	Ag/Fe
ECC (n = 14)			(n = 7)	(n = 3)	(n = 3)
Mean	71 ± 9	114 ± 13	2.3 ± 0.2	0.56 ± 0.5	2.1 ± 1
Range	58–86	91–137	2.1 ± 2.7	0.20–1.1	1.4–3.3
WCC (n = 7)			(n = 5)	(n = 3)	(n = 3)
Mean	36 ± 18	123 ± 49	1.7 ± 0.5	0.22 ± 0.1	0.84 ± 0.1
Range	13–64	34–165	1.3–2.5	0.15–0.33	0.73–0.93
Continental Crust	12.2	18	0.37	0.012	0.017

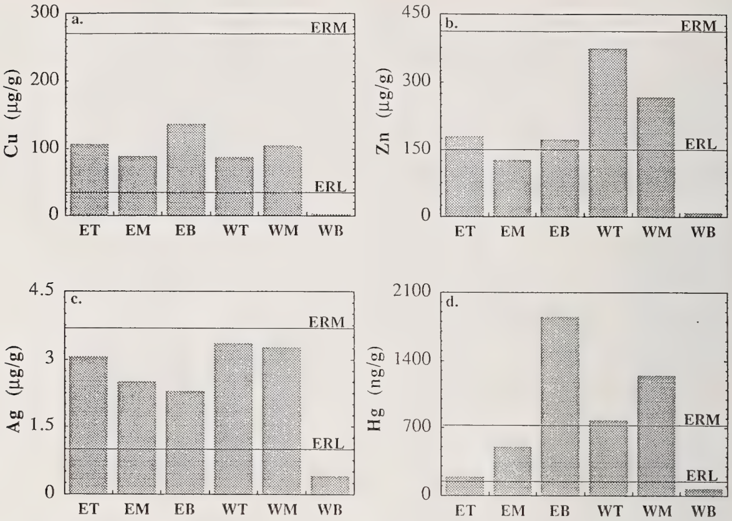


FIG. 2. Comparison of (a) Cu, (b) Zn, (c) Ag, and (d) Hg with ERM and ERL values (Long et al. 1995) at ECC and WCC (E=ECC; W=WCC; T=Top; M=Middle; B=Bottom).

ination does not contribute significantly to adverse biological effects in Crane Creek.

Sediment accumulation rates are important to our understanding of the temporal origin of trace metals and other contaminants. Using Pb-210 and Cs-137 radioisotopes, we can determine approximate core ages. Cs-137 is an isotope that is a product of nuclear fission. Therefore, the isotope would not be present in sediments older than the first significant nuclear fission reaction which occurred in the early 50s and reached a maximum in 1963. We can use these milestones as an aid in determining the relative age of our sediment. A linear decrease in the natural logarithm (ln) of excess Pb-210 with depth will provide an average rate of accumulation provided the sediments are not older than the range of the technique, which is 100–120 years (Trefry et al., 1992).

In the ECC core, Cs-137 does not decrease significantly enough to determine the pre-1950s depth (Fig. 3). This is most likely due to mixing of recent sediments. A non-linear decrease in the excess Pb-210 is one other indication that only recent sediments occupy this location; the calculated sediment accumulation rate of ~ 1.6 cm/y has a high error (r=0.588), yet suggests that these sediments were deposited less than 40 years ago.

In the WCC core, a different sediment record was observed. The Cs-137 profile reached a maximum around 13 cm and decreased to zero between 30 and 41 cm, indicating pre-1950s sediments (Fig. 3). From the excess Pb-210 data, an accumulation rate of 0.4 cm/y was calculated. This is an average for the entire core of depth 45 cm. Trace metals for this core showed

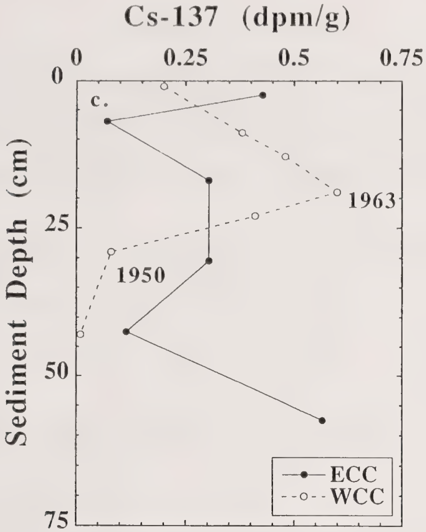


FIG. 3. Profile of Cs-137 with depth for ECC and WCC sediment cores.

a general trend of decreasing concentration with depth indicating contamination took place in recent history.

CONCLUSIONS—Metal contamination was identified in both cores for Ag, As, Cu, Hg and Zn. These metals were found at concentrations greater than 30 times natural background levels. Comparison of metal concentrations with ERL and ERM values (Long et al., 1995) suggest frequent adverse biological effects due to Hg and occasional adverse biological effects due to Ag, Cu and Zn in both cores. Sediment age dating suggested that the ECC core is younger than 30 years and is well mixed, with a sediment accumulation rate of ~1.5 cm/yr. This value is questionable, however, due to poor correlation. The WCC core is not mixed, and has a sediment accumulation rate of 0.4 cm/yr. Metal concentration near the bottom of this core approach natural levels, and increase nearer the top, suggesting that anthropogenic metal contamination has occurred recently. This limited study of heavy metal contamination in Crane Creek has indicated that significantly elevated levels of metals exist in Crane Creek, and may be causative of adverse biological effects.

ACKNOWLEDGMENTS—We thank Kelly Naito for her invaluable assistance in digesting and analyzing our samples, and we appreciate the help of Simone Metz and Bob Trocine in analyzing As and Hg, and for helping with calculations. We aprpeciated the helpful comments of Brad Moran. We especially thank John Trefry for his instruction and guidance throughout the project.

LITERATURE CITED

Bloom, H. and G. M. Ayling. 1977. Heavy metals in the Derwent Estuary. Environ. Geo. 2(1):3–22.

Bruland, K. W., K. Bertine, M. Koide, and E. D. Goldberg. 1974. History of heavy metal pollution in Southern California Coastal Zone. Environ. Sci. Technol. 8:425–432.

Forstner, U. and G. T. W. Wittman. 1979. Metal Pollution in the Aquatic Environment. Springer-Verlag. New York, NY.

Goldberg, E. D., E. Gamble, J. J. Griffin and M. Koide. 1977. Pollution history of Narragansett Bay as recorded in its sediments. Estuar. Coastal Mar. Sci. 5:549–561.

Kane, J. S., S. A. Wilson, J. Lipinski, and L. Butler. 1993. Leaching procedures: A brief review of their varied uses and their application to selected Standard Reference Materials. Amer. Environ. Lab. 5(4):14–15.

Kouadio, I. and J. H. Trefry. 1986. Sediment trace metal contamination in the Ivory Coast, West Africa. Water, Air, Soil Poll. 32:145–154.

Long, E. R., D. D. MacDonald, S. L. Smith and F. D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ. Manage. 19(1):81–97.

Nishimura, H. and M. Kumagai. 1983. Mercury pollution of fishes in Minamata Bay and surrounding water: Analysis of pathway of mercury. Wat. Air Soil Poll. 20:401.

Papakostidis, G., A. P. Grimanis, D. Zafiropolous, G. B. Griggs, and T. S. Hopkins. 1975. Heavy metals in sediments from the Athens sewage outfall. Mar. Poll. Bull. 6:136.

Rao, D. 1987. Surface water hydrology. In: J.S. Steward and J.A. VanArman, 1987. Indian River Lagoon Joint Reconnaissance Report. Department of Environmental Regulation and OCRM/NOAA, Final Report CM-137, pp. 2-1-1-40.

Schropp, S. J., F. G. Lewis, H. L. Windom, J. D. Ryan, F. D. Calder, and L. C. Burney. 1990. interpretation of metal concentrations in estuarine sediments of Florida using aluminum as a reference element. Estuaries 13:227–235.

Trefry, J. H., S. Metz, R. Trocine, N. Iricanin, D. Burnside, N. Chen, and B. Webb. 1990. Final Report to the St. John's River Water Management District. Florida Institute of Technology, Melbourne, FL.

——— and B. J. Presley. 1976. Heavy metals in sediments from San Antonio Bay and the northwest Gulf of Mexico. Environ. Geo. 1:283–294.

———, Nai-Chi Chen, R. P. Trocine and S. Metz. 1992. Impingement of organic-rich contaminants in Manatee Pocket, Florida. Florida Scient. 55:160–171.

Florida Scient. 60(2): 81–88. 1997
Accepted: November 6, 1996.

OBSERVATIONS OF INSECTS ASSOCIATED WITH AN INFESTATION OF SAND PINE (*PINUS CLAUSA*) BY THE APHID *CINARA PINIVORA*

R. M. Clouse[1], B. Ferster[1], and M. A. Deyrup

Archbold Biological Station, P.O. Box 2057,
Lake Placid, FL 33862 USA

Abstract: *This report provides observations of insect visitors to an infestation of sand pine (*Pinus clausa*) by the aphid* Cinara pinivora, *along with a list of collected specimens. Yellow jackets (*Vespula squamosa*) and other Hymenoptera were the most common visitors. Unlike many other aphid infestations, however, only one species of ant was collected (*Camponotus abdominalis floridanus*). Night collections consisted of over 90% male mosquitoes (*Culex *prob.* nigripalpus*). For some species, this report may constitute a rare observation of adult feeding behavior.*

Many insects feed on the carbohydrate-rich anal secretions of aphids (Krombein, 1951; Zoebelein, 1956a; Way, 1963; Idoine and Ferro, 1988). These secretions, called "honeydew" (Klingauf, 1987), can be a major carbohydrate resource for some ant species (Zoebelein, 1956b; Way, 1963; Nielsson et al., 1971) and an incidental carbohydrate resource for other insects (Idoine and Ferro, 1988). Honeydew-feeding insects, in turn, may attract predators and parasites (Zoebelein, 1956b; Togashi, 1987). Therefore, a concentrated food web based on a small amount of infested plant material can emerge and become established quickly. Here we report observations of an infestation of sand pine (*Pinus clausa*) by the aphid *Cinara pinivora* (Wilson).

Large numbers of yellow jackets (*Vespula squamosa*) were first noticed around one *P. clausa* tree on 10 June 1993 at the Archbold Biological Station, Highlands Co., Fl. Archbold Biological Station is located on the south end of the Lake Wales Ridge in South Central Florida. Ridge habitat is xeric scrubland characterized by the presence of *P. clausa* (Abrahamson et al., 1984; Myers, 1990). *Cinara pinivora,* in contrast, is widely distributed from Florida North to Canada. (Pepper and Tissot, 1973). The persistent swarm of *V. squamosa* enticed us to investigate the source of interest and to discover a tree infested with *C. pinivora.* Closer inspection revealed that the insect aggregation actually consisted of many insect species.

---

[1] Current address: Everglades National Park, Research, 40001 SR 9336, Homestead, FL 33034

TABLE 1. Insects found associated with an aphid- (*Cinara pinivora*) infested sand pine (*Pinus clausa*).

Order	Family (Subfamily)	Species
Hymenoptera	Chrysididae	*Chrysis fuscipennis* Brulle[40]
	Colletidae	*Hylaeus confluens* (Smith)[15,19,38]
	Eumenidae	*Monobia quadridens* (Linnaeus)[12,36]
		Pachodynerus erynnis (Lepeletier)[10,12,13,17,22,28,29,31,32,33]
		Parancistrocerus perennis anacardivora (Rohwer)[6,11,24,25,28]
	Formicidae	*Camponotus abdominalis floridanus* (Buckley)[43]
	Ichneumonidae	*Gnamptopelta obsidianator austrina* (Cresson)
		Listrognathus glomeratus Townes
	Mutillidae	*Dasymutilla vesta sappho* (Fox)[18,36,38]
		Sphaeropthalma pensylvanica (Lepeletier)[38]
	Pompilidae	*Paracyphononyx funereus* (Lepeletier)[2,32]
		Sericopompilus apicalis (Say)[2,3,16,31]
	Rhopalosomatidae	*Rhopalosoma nearcticum* Brues
	Sphecidae	
	(Crabroninae)	*Ectemnius decemmaculatus* (Fox)[42]
		Ectemnius excavatus (Fox)[7,42]
	(Larrinae)	*Tachytes validus* Cresson
		Trypargilum collinum (Smith)
		Trypargilum clavatum johannis (Richards)[26]
	(Nyssoninae)	*Bicyrtes quadrifasciata* (Say)[12,22,26,31,32,34]
	(Philanthinae)	*Cerceris robertsonii* (Say)[7]
		Cerceris tolteca Saussure[12,28,30,34]
	(Sphecinae)	*Chalybion californicum* (Saussure)[20,36]
		Eremnophila aureonotata (Cameron)[33]
		Sceliphron caementarium (Drury)[36]
	Tiphiidae	*Myzinum maculatum* (Fabricius)[8,13,20,22,25,26,31,32,33]
		Tiphia floridana Robertson[5,15,16,31,34]
	Vespidae	*Mischocyttarus mexicanus* (Saussure)
		Polistes exclamens Viereck
		Vespula squamosa (Drury)[1]
Diptera	Anthomyiidae	undetermined genus
	Calliphoridae	*Phaenicia* sp.
		undetermined genus
	Cecidomyiidae	undetermined genus[37]
	Ceratopogonidae	*Atrichopogon* spp.[37]
		Forcipomyia fulginosa (Meigen)
		Forcipomyia glauca Macfie
	Chloropidae	*Liohippelates pusio* (Loew)[5,13,31]
	Culicidae	*Culex* prob. *nigripalpus*[37,38,41]
		Mansonia spp.[37,38]
	Conopidae	*Physoconops* sp.[14]
	Lauxaniidae	*Camptoprosopella* sp.
	Milichiidae	*Milichiella* sp.
		Pholeomyia sp.
	Sarcophagidae	undetermined genera
	Sepsidae	*Palaeosepsis pusio* (Schiner)[13,31]
	Stratiomyidae	*Stratiomys floridensis* Steyskal
	Syrphidae	*Palpada agrorum* (Fabricius)[6,9,13,17,19,21,23,26,32]

TABLE 1. *Continued.*

Order	Family (Subfamily)	Species
	Tachinidae	*Paradidyma* sp.[39]
		Trichopoda sp.[35]
	Tabanidae	*Tabanus nigripes* Wiedemann
Coleoptera	Alleculidae	*Hymenorus heteropygus* Fall
	Elateridae	*Melanotus* prob. *morosus* Candeze[37]
	Helodidae	*Cyphon* sp.
	Phylacridae	*Acylomus* sp.
	Scarabaeidae	*Diplotaxis bidentata* LeConte
Lepidoptera	Pyralidae	*Spoladea recurvalis* (Fabricius)
		Herpetogramma bipunctalis (Fabricius)
		two unidentified microlepidoptera spp.
Neuroptera	Chrysopidae	*Notida pavida* (Hagen)
Orthoptera	Tettigoniidae	*Odontoxiphidium apterum* Morse

[1] Adults reported as honeydew visitors by Akre and co-workers (1981).

[2] Adults reported common on flowers (Evans, 1951).

[3] Adults reported common on honeydew (Evans, 1950).

[4] Allen (1966) reports that it has also been collected on *Phylloxera* honeydew on *Quercus* by Krombein, on mango flowers by Needham, and on honeydew on thistle.

[5] Also collected at Archbold at honeydew of *Idioderma virescens* (Homoptera: Membracidae).

[6] Also collected at Archbold from *Aralia spinosa* flowers.

[7] Also collected at Archbold from avocado flowers.

[8] Also collected at Archbold from *Balduina angustifolia* flowers.

[9] Also collected at Archbold from *Befaria racemosa* flowers.

[10] Also collected at Archbold from *Bidens alba* flowers.

[11] Also collected at Archbold from *Crotonopsis linearis* flowers.

[12] Also collected at Archbold from *Eriogonum floridanum* flowers.

[13] Also collected at Archbold from *Eryngium cuneifolium* flowers.

[14] Also collected at Archbold from *Eupatorium mohrii* flowers.

[15] Also collected at Archbold from *Euthamia minor* flowers.

[16] Also collected at Archbold from extrafloral nectaries on *Crotalaria pallida.*

[17] Also collected at Archbold from *Gerberia fruticosa* flowers.

[18] Also collected at Archbold from honeydew on *Carya floridana.*

[19] Also collected at Archbold from *Hypericum edisonianum* flowers.

[20] Also collected at Archbold from *Ilex glabra* flowers.

[21] Also collected at Archbold from *Lachnanthes caroliniana* flowers.

[22] Also collected at Archbold from *Licania michauxi* flowers.

[23] Also collected at Archbold from *Opunita compressa* flowers.

[24] Also collected at Archbold from *Palafoxia feayi* flowers.

[25] Also collected at Archbold from *Parthenocisus quinquefolia* flowers.

[26] Also collected at Archbold from *Persea humilis* flowers.

[27] Also collected at Archbold from *Pityopsis graminifolia* flowers.

[28] Also collected at Archbold from *Polygonella gracilis* flowers.

[29] Also collected at Archbold from *Polygonella robusta* flowers.

[30] Also collected at Archbold from *Richardia scabra* flowers.

[31] Also collected at Archbold from *Serenoa repens* flowers.

[32] Also collected at Archbold from *Solidago chapmanii* flowers.

[33] Also collected at Archbold from *Warea carteri* flowers.

[34] Also collected at Archbold from *Ximenia americana* flowers.

[35] Also collected at Everglades National Park from *Sabal palmetto* flowers by Clouse and Ferster.

[36] Also collected by Krombein (1951) visiting *Toumeyella liriodendri* honeydew.

[37] Collected at night.

[38] Male specimen/mostly males collected.

[39] Other *Paradidyma* specimens, perhaps the same species, have been collected at Archbold from *Idioderma* (Homoptera: Membracidae) honeydew.

[40] Parasite of *Sceliphron caementarum* (Hymenoptera: Sphecidae), exotic to Archbold Biological Station.

[41] Photographed visiting extrafloral nectaries of *Ricinus communis* (Taylor and Foster, 1996).

[42] Adults hunt Diptera.

[43] Worker only.

METHODS—Insects were collected by sweep netting the lower branches of the infested tree. Collections were made haphazardly between 0600 and 1800 hours between 5 July and 7 July 1993. Two collections were made at night. The branches of two nearby sand pines were also swept both during the day and at night to gauge the degree to which insect abundance was due to aphid honeydew and not some characteristic of sand pine. Collected specimens were identified to species where possible, and any other information about their feeding habits as determined from the literature, the Archbold insect collection, or the Everglades National Park collection, was noted (Table 1). All specimens were deposited in the Archbold Biological Station insect collection.

RESULTS—Over 60 insect species from 34 families and six orders were discovered visiting the aphid-infested pine tree. *Vespula squamosa* was an abundant visitor, although the closest known yellowjacket nest was several hundred meters away (Clouse, personal observation). We found them to be the first visitors at dawn and their visits continued until sundown. Only one ant specimen was collected despite a thorough search of branches and needles. Ants are the most thoroughly studied exploiters of aphid honeydew, but they were almost absent from this collection; it has been suggested that they may not tend this aphid species (Pepper and Tissot, 1973). It should be stressed, however, that given the wide range of *Cinara pinivora* and the paucity of information on its ecology, ant interactions may be absent only from the literature, not nature. Nighttime collections were dominated by male mosquitoes. Although it is logical that male mosquitoes might use honeydew as an energy source, and this species has been photographed visiting an extrafloral nectary (Taylor and Foster, 1996), this is the first time to our knowledge male visitation of honeydew has been reported. No insects were collected from uninfested sand pines.

Most insects were collected without noting their behavior in the sand pine, so definitive statements about their motives are not possible. However, yellowjackets could clearly be seen licking the glazed leaves, and common flower and honeydew visitors, like Eumenines (Hymenoptera: Vespidae) and Syrphids in the genus *Palpada* (Diptera) were most likely attracted to honeydew as a carbohydrate source. Moreover, male mosquitoes were also most likely attracted by the honeydew directly. Conversely, in addition to ingesting honeydew, Crabronines (Hymenoptera: Sphecidae) could have been hunting for flies attracted to the honeydew, and *Bicyrtes quadrifasciata* (Sphecidae: Nyssoninae) might have been hunting for Hemipterans, although we did not collect any true bugs at this infestation.

ACKNOWLEDGMENTS—We thank K. Krombein, H. McKeithen, D. Hall, D. Wahl, and the late W. Wirth, for assistance in insect identification.

LITERATURE CITED

ABRAHAMSON, W. G., A. F. JOHNSON, J. N. LAYNE, AND P. A. PERONI. 1984. Vegetation of the Archbold Biological Station, Florida: An example of the southern Lake Wales Ridge. Florida Scient. 47:209–250.

AKRE, R. D., A. GREENE, J. F. MAC DONALD, P. J. LANDOLT, AND H. G. DAVIS. 1981. The Yellowjackets of America North of Mexico. USDA Agriculture Handbook 552, 102 pp.

ALLEN, H. W. 1966. Revision of the Tiphiinae of Florida (Hymenoptera: Tiphiidae) of eastern North America. Trans. Am. Entomol. Soc. 92:231–356.

EVANS, H. E. 1950. A taxonomic study of the Neartic spider wasps belonging to the tribe Pompilini (Hymenoptera: Pompilidae) I. Trans. Am. Entomol. Soc. 75:133–270.

———. 1951. A taxonomic study of the Neartic spider wasps belonging to the tribe Pompilini (Hymenoptera: Pompilidae) III. Trans. Am. Entomol. Soc. 77:203–340.

IDOINE, K. AND D. N. FERRO. 1988. Aphid honeydew as a carbohydrate source for *Edovum puttleri* (Hymenoptera: Eulophidae). Environ. Entomol. 17:941–944.

KLINGAUF, F. A. 1987. Feeding, adaptation and excretion. Pp. 225–254. *In:* Minks, A. K. and P. Harrewijn (eds.). Aphids: Their Biology, Natural Enemies and Control. Elsevier, Amsterdam.

KROMBEIN, K. V. 1951. Wasp visitors of tulip-tree honeydew at Dunn Loring, Virginia. Annals Entomol. Soc. Am. 44:141–143.

MYERS, R. L. 1990. Scrub and high pine. Pp. 150–193. *In:* Myers, R. L. and J. J. Ewel (eds.). Ecosystems of Florida. UCF Press, Orlando, FL.

NIELSSON, R. J., A. P. BATKAR, AND H. A. DENMARK. 1971. A preliminary list of ants associated with aphids in Florida. Fl. Entomol. 54:245–248.

PEPPER, J. O. AND A. N. TISSOT. 1973. Pine-feeding species of *Cinara* in the eastern United States (Homoptera: Aphididae), Fl. Ag. Exper. Monograph series. Institute of Food and Agriculture Sciences, UF, Gainesville.

TAYLOR, R. M. AND W. A. FOSTER. 1996. Spider nectivory. Am. Ent. 42:82–86.

TOGASHI, I. 1987. Insects associated with aphid, *Toxoptera odinae,* and honeydew secreted by *T. odinae.* Trans. Shikoku Entomol. Soc. 18:315–326.

WAY, M. J. 1963. Mutualism between ants and honeydew-producing Homoptera. Ann. Rev. Entomol. 8:315–326.

ZOEBELEIN, G. 1956a. Der Honigtau als Nahrung der Insekten. Teil II. Z. Angew. Entomol. 39: 129–167.

———. 1956b. Der Honigtau als Nahrung der Insekten. Teil I. Z. Angew. Entomol. 38:369–416.

Florida Scient. 60(2): 89–93. 1997
Accepted: October 2, 1996.

A PRELIMINARY ANALYSIS OF NEOGENE DEPOSITIONAL ENVIRONMENTS IN BROWARD COUNTY, FLORIDA

Charles W. Finkl, Jnr. and Luciana S. Esteves

Department of Geology, Florida Atlantic University,
P.O. Box 3091, Boca Raton, FL 33431

Abstract: *This study of borehole logs summarizes some preliminary interpretations of the geologic evolution of the Broward County (Florida) area in terms of the paleo-environmental conditions under which Neogene (later Tertiary, Miocene and Pliocene) and Pleistocene sedimentary deposits formed. The coastal geological framework of Broward County consists predominantly of thick marine shallow-water sequences alternating with thin fresh- and brackish-water deposits. The lithologic components of dominant stratigraphic sections mostly contain carbonate rocks, but clastic deposits are more important in older sequences and in eastern Broward along coastal sectors. This lithologic relationship probably reflects local paleo-environmental evolutionary trends that changed from: (a) offshore marine deposits (silts, clays and mixtures) during the early Miocene, to (b) nearshore carbonates and inner shelf sands during the late Miocene and Pliocene, to (c) subaerial and submerged coastal deposits during the Pleistocene. Changes in environmental conditions and associated sedimentary deposits were conditioned by variations in shoreline position and water depth.*

Extensive and nearly continuous limestone deposition has dominated sedimentologic evolution on the southern Florida Platform since the early Cretaceous, as shown by exploratory drilling (Applegate et al., 1981). Although the region was tectonically stable for long periods of time, the higher topography in the eastern part of Florida and general westward thickening of the Pleistocene section (Perkins, 1977) led some workers to suggest that westward tilting of the Florida Platform took place during the Pliocene and early Pleistocene (e.g. Parker and Cooke, 1944; Parker et al., 1955; Shinn et al., 1989). The thick limestone that underlies south Florida has undergone neither tectonic deformation nor significant erosion during the past 15,000 years (Lidz and Shinn, 1991). Although there have been extensive studies of the Florida reef tract that ornaments the outer margin of the shallow continental shelf (e.g. Hoffmeister, 1974; Lidz and Shinn, 1991) comparatively fewer studies have featured discussion of environments of deposition that lie westward of the present coastline. This report summarizes some preliminary results of detailed lithologic studies of bore logs for the area occupied by Broward County (Fig. 1) along the lower east coast of the Florida peninsula.

The complexity of the lithologic record in Broward County is perhaps the largest contributor to the lack of detailed knowledge of local subsurface

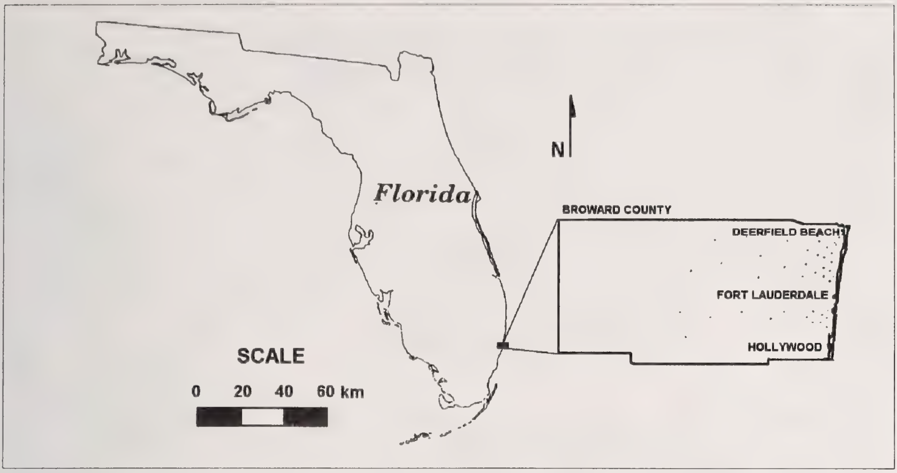


FIG. 1. Location of Broward County on the southeast coast of Florida. The Atlantic Coastal Ridge, a major topographic feature in the county, lies parallel to the shore and is the site of intense urban development which has contributed to the salt-water intrusion problem.

geology. Because such complexity affects many hydrological properties of surface and groundwater flow, viz. infiltration, percolation, flux rates and direction of flow, lithological and stratigraphic variations are crucial to better understanding of problems related to salt-water intrusion in aquifers and quality of groundwater supply to eastern Broward, especially in the vicinity of Hollywood and Deerfield Beach. Analysis of extensive core log data, coupled with ancillary information, provides an opportunity to estimate the nature of variations in depositional sedimentary paleo-environments that occurred throughout the Neogene and Pleistocene in the general Broward County area. The advantage of attempting to unravel the complexities of changing coastal environments through time is that some of these paleoenvironments may be directly related to the saltwater intrusion problem. Some paleosystems such as tidal inlets, which are comprised of porous carbonate sands, are today found at depth as cross-shore features that may act as conduits for the landward movement of marine waters (Finkl and Restrepo, 1993).

METHODS—Identification of depositional environments was based on the description and interpretation of sedimentary rock properties (lithological analysis), as described by Allen (1982) and Collinson and Thompson (1989), and stratigraphic (vertical and horizontal) relations among formations. Stratigraphic interpretations logically follow in the development of a preliminary model for the coastal geological framework, as summarized by Krumbein and Sloss (1963) and by Friedman and co-workers (1992). Lithologic information was compiled from published borehole logs summarized in Causaras (1985), Fish (1988) and Florida Geological Survey reports as well as from unpublished private (water well) drilling companies. In this effort, 68 borehole logs were built-up from 4,367 m (14,328 feet) of raw (uninterpreted) lithologic data. The geographic location of primary logs in Broward County is shown in Fig. 2.

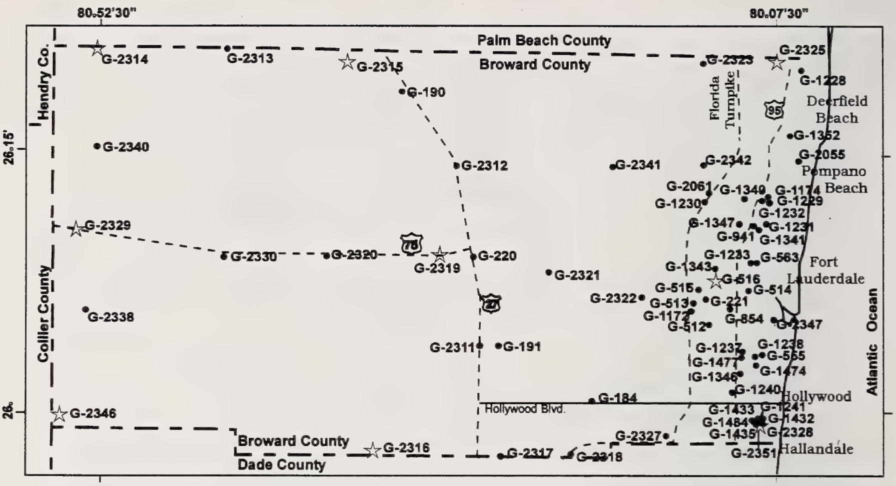


FIG. 2. Geographic location of boreholes that were used to determine stratigraphic relationships and the nature of sedimentary environments in Broward County, Florida. Logs that were used to compile the isometric diagram in Fig. 3 are shown by an open star as follows: G-2325 (NE). G-516 (CE), G-2351 (SE), G-2315 (NC), G-2319 (C), G-2316 (SC), G-2314 (NW), G-2329 (WC), and G-2346 (SW) where N = north, S= south, E = east, W = west, and C = central.

The spatial relationships (both horizontal and vertical gradation and sequences) between deposits were based on nine cross-sections that crisscrossed Broward County. Three cross sections, each comprised by three representative logs from eastern, central, and western Broward are shown in a block-diagram format (Fig. 3) to illustrate the main geospatial relationships deduced from this study of sedimentary deposits. The locations of the logs are geographically correct and elevations adjusted to mean sea level (NGVD, 1927). The logs and cross sections were constructed using RockWorks® software, a specialized geological graphics program.

Environments of deposition were inferred from various sedimentary properties such as particle size (including grading), rock color, chemical composition (mineralogy), weathering, and fossils. Criteria for recognition of freshwater limestones in marine carbonate sequences, reviewed by Halley and Rose (1977), were applied where appropriate in this study. Evidence of marine deposition (formation) was associated with accumulations of phosphorite, which was widely distributed in many sequences and ranged up to 30% in some beds, and fossil mollusks, barnacles, bryazoans, corals, and echinoid fragments as reported in the core logs (e.g. *Pecten* sp., *Turritella* sp., *Ostrea* sp.). Fossils reported in our logs were compared to lists of marine species (macro- and microfauna) common to the area as given in Parker and co-workers (1955) for U.S. Geological Survey test wells in southeast Florida. Solution holes in limestone, neomorphic calcite, and travertine (caliche) crusts are widely reported as being characteristic of subaerially weathered (chemically solutioned) limestone surfaces (Sweeting, 1973) and are here likewise correlated with unconformities or diastems in the sedimentary record. Marls often contain freshwater gastropod shells (e.g. *Helisoma* sp., *Planobis* sp., *Ameria* sp.) but in some places carbonaceous zones show remnants of roots, stems, and other organic debris that suggests former brackish-water conditions or mangrove swamps (Parker et al., 1955). Some marls are found under Holocene organic soils and above the rock floor of the Everglades, while others are often intercalated with layers of organic material, peat, or muck. Parker and co-workers (1955) point out that these marl layers pinch out or grade into the organic layers both horizon-

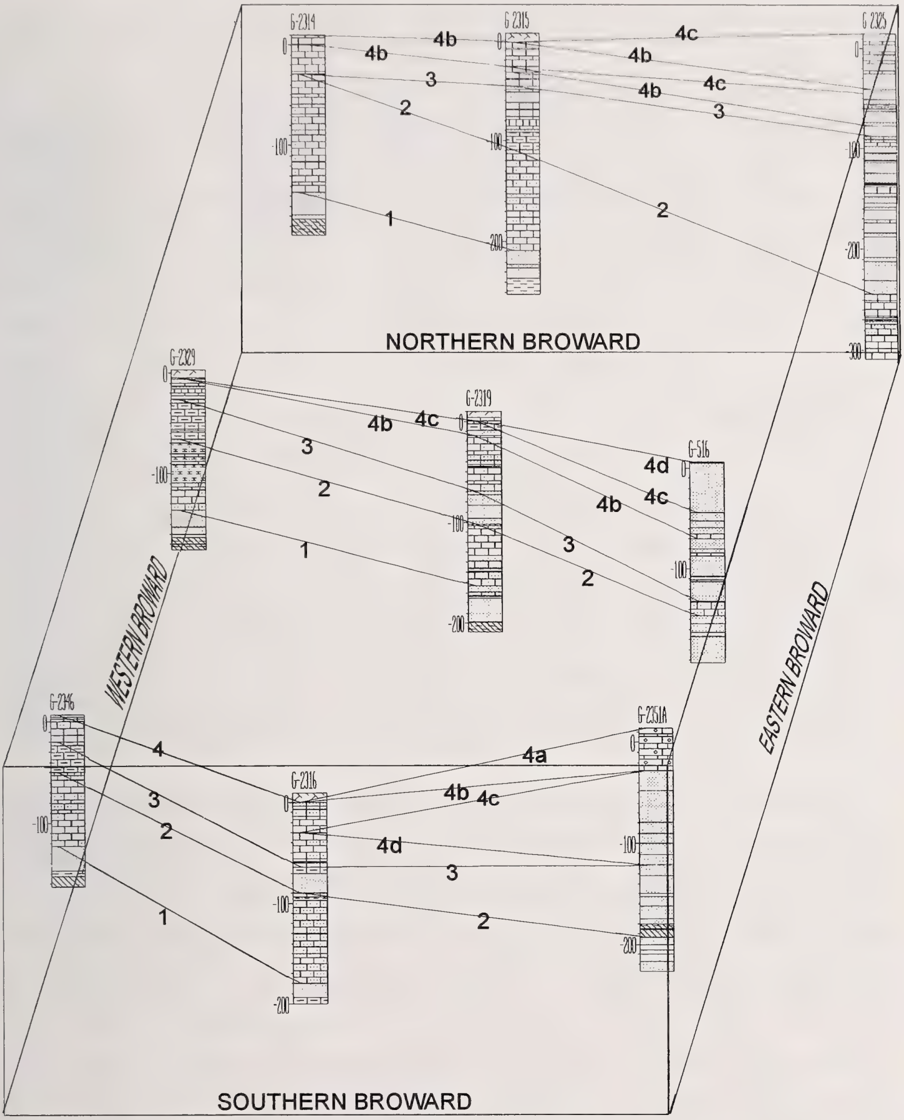


FIG. 3. Isometric (3-D) diagram showing nine repesentative lithologic logs for northern, central, and southern cross-sections in Boward County. The setting reference for each bore hole was mean sea level according to the National Geodetic Vertical Datum (NGVD) of 1929. Because elevations of the logs are adjusted to NGVD (elevation of the present landsurface minus the depth of the log), it is possible to show the relative positions of geological formations which are linked between logs by straight lines. The geographic locations of the logs are georectified to state planar coordinates to facilitate spatial comparisons of lithologic materials. Stratigraphic sequences are indicated in terms of relative chronologies by Arabic numbers from oldest to youngest as follows: (1) lower Pliocene (or lower Tamiami Formation), (2) upper Pliocene (or upper Tamiami Formation), (3) lower Pleistocene (including part of the Fort Thompson Formation), and (4) upper Pleistocene. The upper Pleistocene (4) is further subdivided by lithologic composition for (a) Miami Oolite (Miami Limestone), (b) Fort Thompson Formation, (c) Anastasia Formation, and (d) Pamlico sands.

tally and vertically, thus indicating an origin closely related to the deposition of Everglades peat and muck.

Results and Discussion—Based primarily on fossil faunal assemblages seen in shell remains and the chemical properties of rocks, geologists have long recognized that the stratigraphic succession in southern Florida formed predominantly, with few exceptions, under a marine environment (e.g. Parker and Cooke, 1944; Hoffmeister, 1974; Enos and Perkins, 1977; Parker et al., 1955). The exceptions occur in the lacustrine and swamp deposits of the Lake Okeechobee-Everglades depression which occurs partly in western Broward County. These deposits include freshwater beds of the Fort Thompson Formation, the freshwater Lake Flirt marl, and organic soils, mostly Everglades peats and mucks. The clays of southern Florida (except for the surficial red-colored laterites occupying filled solution holes in karstified limestones in the "Redlands" area of Dade County) are commonly greenish in color, calcareous in composition (often with 10%–15% phosphorite), and of marine origin (they contain a shallow-water fossil fauna indicative of warm subtropical conditions) (Parker et al., 1955). The Fort Thompson Formation forms the floor of the Lake Okeechobee-Everglades depression as far east as the Atlantic Coastal Ridge (which is comprised, in part, by the Anastasia and Miami Limestone formations) where its marine beds merge with the main mass of the Anastasia Formation, a relationship which has been clearly demonstrated in the vicinity of Fort Lauderdale (Parker et al., 1955).

In summary, the Neogene geological framework of Broward County consists of alternating fresh, brackish-water, and marine deposits laid down under generally shallow water conditions (e.g. Enos and Perkins, 1977; Gleason et al., 1984). Shoreline processes were the major factors in dispersing detrital materials and consequently the changes in depositional characteristics largely depended on variations in shoreline position and sea-level oscillations (Lidz and Shinn, 1991) which must have been a major factor in determining the nature and scale of depositional sequences.

Generally, lower sections of the logs comprise fine-grained (clays and silts) calcareous marine sediments, while the upper sedimentary layers are formed under nearshore (beachface) depositional conditions. Sea-level fall, associated with marine regressions, typically resulted in the development of a nearshore fauna associated with fringing coral reefs of the type described by Halley and Evans (1983) and sometimes in clastic depositional sequences of quartzose sand, as reported for example by Lidz and Shinn (1991) for parts of the Florida reef tract on the outer margins of the shallow continental shelf to the south in Dade County. The presence of fine-grained (often micritic) materials at the base of most logs suggests deposition under low energy conditions, probably on what was then the outer continental shelf. Following that, a regression clearly recorded in many logs (see Figs. 3 and 4), resulted in changing depositional conditions from open marine to near-

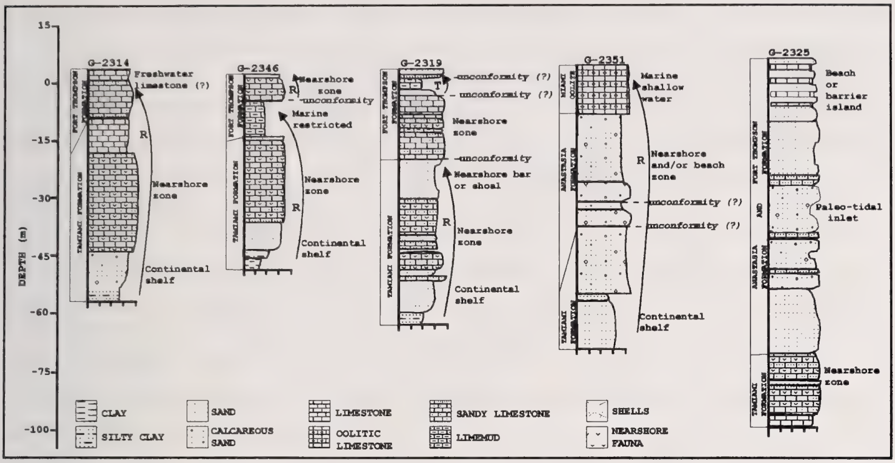


FIG. 4. Diagramatic sections based on lithologic logs showing some salient paleo-environmental conditions in Broward County from Miocene through the Holocene. Logs G-2314, G-2346, G-2319, G-2351 and G-2325 in northwest, southwest, central, southeast, and northeast Broward (cf Figs. 2 and 3) respectively illustrate stratigraphic sequences and environmental changes through time. The direction of regressive sequences (R), shown by arrows, is associated with sea-level falls and progradations (seaward movement) of shorelines. Transgessions (T) are associated with sea-level rises which flooded parts of the platform. Unconformities in the sections mark intervals where parts of the sedimentary record are missing (eroded away) and where formations have been subaerially exposed as landsurfarces.

shore environments in central and west Broward, while the easternmost logs continue to present characteristics of continental shelf deposits. Regressions within the Tamiami Formation, described by Peck and co-workers (1976) and Webb and co-workers (1978), were associated with glacio-eustatic falls in sea level. During mid-Tamiamian time (at the time represented by the mid-upper Tamiami Formation), sandy limestones and reefal fauna were broadly deposited; no subaerial deposits are recorded in the logs. During the early Pleistocene, the type and sequence of depositional environments increases when subaerial (terrestrial) deposits were laid down and intercalated with marine sediments, as reported by Halley and Evans (1983) for the Atlantic Coastal Ridge and by Lidz and Shinn (1991) for the Florida reef tract. The nearshore sediments were deposited on top of offshore sands in the upper Tamiami Formation (e.g. logs G-2314, G-2319, and G-2346, in Figs. 3 and 4). In this shallowing upward sequence the previous nearshore deposits (containing shallow water mollusks, pellets, bryozoans, and echinoid fragments) were in turn buried by freshwater deposits such as lime muds and cavity-filling neoformed calcite as described by Causaras (1985) and Fish (1988). A large sand bar (or shoal) was also present in central Broward at this time. The shoal may have acted as a barrier to water circulation, resulting in brackish conditions in eastern Broward, as observed by Peck and co-workers (1976) through interpretation of paleontological data. These conditions may have been favorable for the deposition of calcium carbonate that formed the lime mud layers in a restricted-circulation marine environment as described in log G-2346 (Fig. 3). Freshwater limestones, found in logs G-2314 (Fig. 3) and G-2313, and presence of younger cavity-filling calcite in some vughy deposits, and calcrete, indicate subaerial exposure in northwestern Broward.

Unconformities, which represent gaps in the sedimentary record, occur more frequently in the logs than does evidence of subaerial deposits. Missimer and co-workers (1994) estimate that about one-third of Cenozoic time is missing from the stratigraphic record in southern Florida; this erosional loss of sediments contributes to the lack of information for a significant part of the local geologic record. The environmental transitions within the Pleistocene are numerous and complex due to erosive events, weathering of the landsurface, and dissolution of limestones that produced karstified landscapes. Evidence of Pleistocene sea-level oscillations in the southern Florida region consists of subsurface subaerial features such as laminated calcrete, peat, root casts, and mold (Lidz and Shinn, 1991). Stratigraphic relationships evident in the borehole logs and recognition of these kinds of features suggest that most of Broward County was completely emerged during mid-late Pleistocene time. Beach sands and eolianites (Pamlico sand) dominated the eastern part of Broward County, while in western Broward peat or muck (wetlands formed by gradual shoaling) were formed. At this time, freshwater deposits became more frequent and widely spread along the central axis of Broward. Logs G-2325 (Figs. 3 and 4), G-2323, and G-1228 (northeast Broward) show a thick sequence of sands and sandy limestones that suggest the presence of a large tidal pass similar to those described cutting through oolites of the Miami Limestone in the Atlantic Coastal Ridge to the south in Dade County by Hoffmeister (1974) and Halley and Evans (1983).

Previous studies that addressed aspects of the geologic framework in southeastern Florida (e.g. Peck et al., 1976; Webb et al., 1978; Parker et al., 1955; Missimer et al., 1994) focused on the characterization and description of sedimentary formations and specifically considered interpretations of environmental conditions under which the deposits were formed, including those deposits located offshore on the continental shelf (e.g. Hoffmeister, 1974; Lidz and Shinn, 1991). Detailed descriptions of named formations, clear definition of the parameters used to differentiate the formations, and descriptions of formational boundaries were frustated by the lack of exposures for study and the complexity of many sedimentary sequences. Although gathering of more complete and detailed descriptions of the formations was not the main goal of this study, interpretations of sedimentary environments would be simplified if formational boundaries and regional stratigraphies were more completely understood. An important problematic issue focuses on the similar lithology throughout the logs (see, for example, log G-2351 and G-2325 in Fig. 2). In such cases, it is difficult to know whether specific deposits are contemporary or syndepositional in age. For example, the differentiation between nearshore deposits in the Fort Thompson Formation and the upper Tamiami Formation in central Broward County (log G-2319, Fig. 3), or the separation of interbedded layers in the Fort Thompson, Anastasia and Miami Limestone formations in eastern Broward is difficult. Earlier workers have similarly commented on the difficulty in separating formations due to similarities of materials and extensively occurring (transformational) macrofaunal assemblages (e.g. Parker et al., 1955). The lithologic similarity of superposed materials inevitably leads to different interpretations that must per force at least consider: (1) if the sedimentary sequence was formed under similar paleo-environmental regimes and (2) whether the environmental conditions changed with time but produced similar sediments. Loss of parts of the sedimentary record, as evidenced by the presence of discontinuities, further complicates attempts to better understand depositional sequences and environments of formation in this region. Additional studies based on absolute dating methods might help resolve the ages of similar-looking deposits.

CONCLUSIONS—In the broad scheme of things, the general geological framework of Broward County consists largely of marine deposits laid down under shallow-water conditions. The lithology is mostly comprised by carbonate rocks (limestones and sandy limestones), but siliciclastic deposits formed by quartzose sands and sandstones are more important in older sequences and in eastern Broward. This sequence may be a reflection of the environmental evolution in the area that changed from: (a) offshore marine deposits (silts, clays and mixtures) during the early Miocene, to (b) nearshore carbonates and inner shelf sands during the late Miocene and Pliocene, to (c) subaerial and submerged coastal deposits during the Pleistocene. Changes in environmental conditions were thus conditioned by variations in shoreline position and associated changes in water depth. Thus, variations of sea level were the most important factor in determining the depositional characteristics in Broward County.

Due to many similarities among the various deposits, general lack of absolute ages, and apparent continuity of biostratigraphic zones with similar fauna spread throughout a range of materials, many uncertainties remain as does the subjectiveness of interpretations. The application of absolute dating methods would be very useful to precisely define formation boundaries and also to better correlate deposits, which in turn would help to define sedimentary conditions in paleo-environments. For example, Missimer and co-workers (1994) using stable strontium isotopes, and magnetostratigraphic and biostratigraphic dating methods found that the Hawthorn Group deposition began about 30 Ma (late Oligocene) and continued through 4.5 Ma (early Pliocene). These researchers also found that the Tamiami Formation was deposited between 4.5 and 2.8 Ma (Pliocene), in contrast to a previously assigned age of middle to late Miocene.

ACKNOWLEDGMENTS—The borehole data collection and analysis was funded by the Broward Department of Natural Resources Protection (DNRP), Water Management Division, under Contract No. 3EQ00001127. The Coastal Education and Research Foundation, Inc. is thanked for providing computer facilities and specialized software for completing the project. We also gratefully acknowledge Jose Nestor Cardoso for his valuable help and assistance with the computer works. Special thanks go to Fran Henderson, Office of Environmental Services, and Roberto Sanchez (DNRP, Groundwater Division) for logistic support and encouragement.

LITERATURE CITED

ALLEN, J. R. L., (ed.), 1982. Sedimentary Structures: Their Character and Physical Basis, Volume 1. Elsevier, Amsterdam, The Netherlands.

APPLEGATE, A. V., G. O. WINSTON, AND J. C. PALACAS. 1981. Subdivisions and regional stratigraphy of the pre-Punta Gorda rocks (lowermost Cretaceous-Jurassic?) in South Florida. Gulf Coast Assoc. Geol. Soc. 447–453.

CAUSARAS, C. R. 1985. Geology of the Surficial Aquifer System, Broward County, Florida. U. S. Geological Survey, Water-Resources Investigations Report 84-4068.

COLLINSON, J. D., AND D. B. THOMPSON. 1989. Sedimentary Structures. Unwin Hyman, London.

ENOS, P. AND R. D. PERKINS. 1977. Quaternary Sedimentation in South Florida. Geol. Soc. Amer. Memoir 147.

FINKL, C. W., JNR. AND J. RESTREPO. 1993. Final Report: A Preliminary Geological and Surface Geophysical Characterization of the Freshwater-Saltwater Transitional Zone in Eastern Broward County, Florida. (Prepared for Broward Department of Natural Resources Protection, Groundwater Division). Department of Geology, Florida Atlantic University, Boca Raton, Florida, 10p.

FISH, J. E. 1988. Hydrogeology, aquifer characteristics, and ground-water flow of the Surficial Aquifer System, Broward County, Florida. U.S. Geol. Surv., Water Resour. Invest. Rpt. 87-4034.

FRIEDMAN, G. M., J. E. SANDERS, AND D. C. KOPASKA-MERKEL. 1992. Principles of Sedimentary Deposits: Stratigraphy and Sedimentology. Macmillan, New York, NY.

GLEASON, P. J., A. D. COHEN, P. STONE, H. K. BROOKS, R. GOODRICK, AND W. SPACKMAN, JR. 1984. The environmental significance of Holocene sediments from the Everglades and saline tidal plain. Pp. 297–351. *In*: GLEASON, P., (ed.), Environments of South Florida: Present and Past II. Miami Geological Society, Miami, FL.

HALLEY, R. B. AND P. R. ROSE. 1977. Significance of fresh-water limestones in marine carbonate successions of Pleistocene and Cretaceous age. *In*: BEBOUT, D. G. AND R. G. LOUCKS, (eds.), Cretaceous Carbonates of Texas and Mexico. Texas Bur. Econ. Geol., Report of Investigations No. 89.

——— AND C. C. EVANS. 1983. The Miami Limestone: A Guide to Selected Outcrops and their Interpretation. Miami Geological Society, Miami, FL.

HOFFMEISTER, J. E. 1974. Land from the Sea. University of Miami Press, Coral Gables, FL.

KRUMBEIN, W. C. AND L. L. SLOSS. 1963. Stratigraphy and Sedimentation. Freeman, San Francisco, CA.

LIDZ, B. H. AND E. A. SHINN. 1991. Paleoshorelines, reefs, and a rising sea: South Florida, U.S.A. J. Coastal Res. 7(1):203–229.

MISSIMER, T. M. D. F. MCNEILL, R. N. GINSBURG, P. A. MUELLER, J. M. COVINGTON, AND T. M. SCOTT. 1994. Cenozoic record of global sea level events in the Hawthorn Group and Tamiami Formation on the Florida Platform. Geological Society of America (Abstract with Programs) 26(7):151.

PARKER, G. G. AND C. W. COOKE. 1944. Late Cenozoic resources of southeastern Florida, with a discussion of the ground water. Florida Geological Survey Bulletin 27.

———, N. D. HOY AND M. C. SCHROEDER. 1955. Geology. *In*: Pp. 57–125 PARKER, G. G., G. E. FERGUSON, S. K. LOVE, et al., (eds.), Water Resources of Southeastern Florida. U.S. Geological Survey Water Supply Paper 1255.

PECK, D. M., T. M. MISSIMER, AND S. W. WISE. 1976. Glacial-eustatic control of an upper Miocene transgressive-regressive sequence in a low latitude (south-eastern U.S.) coastal plain. Geological Society of America (Abstract with Programs) 8(6):1044–1045.

PERKINS, R. D. 1977. Depositional framework of Pleistocene rocks in south Florida, *In*: Pp. 131–198. ENOS, P. AND R. D. PERKINS (eds.), Quaternary Sedimentation in South Florida, Part II. Geological Society of America Memoir 147.

SHINN, E. A., B. H. LIDZ, J. L. KINDINGER, J. H. HUDSON AND R. B. HALLEY. 1989. A Field Guide: Reefs of Florida and the Dry Tortugas, A Field Trip to the Modern Carbonate Environments of the Florida Keys and the Dry Tortugas. International Geological Congress, IGC Field Trip T176. American Geophysical Union, Washington, D.C.

SWEETING, M. M. 1973. Karst Landforms. Columbia University Press, NY.

WEBB, S. D., S. W. WISE, AND R. WRIGHT. 1978. Late Miocene glacio-eustatic cycles in Florida; marine and fluvio-estuarine sequences. Geological Society of America (Abstract with Programs) 10(7):513.

Florida Scient. 60(2): 94–103. 1997
Accepted: September 13, 1996.

THE IMPACT OF LAKE RESTORATION ON THE ZOOPLANKTON COMMUNITY IN BANANA LAKE, POLK COUNTY, FLORIDA

JOHN A. OSBORNE(1) AND MARY R. EGAN(2)

(1)Department of Biology, University of Central Florida, P.O. Box 25000,
Orlando, Florida 32816;
(2)Glatting, Jackson, Kercher, Anglin, Lopes, Rinehart, Inc.,
33 East Pine Street, Orlando, Florida 32801

ABSTRACT: *Zooplankton were monitored in Banana Lake between January, 1990 and March, 1992 to evaluate the impact of lake restoration by hydraulic dredging. Zooplankters were collected on a monthly basis at eight stations using an 8.1 L Kemmerer water sampler. The samples were concentrated by straining the samples through a #20 nylon bolting cloth zooplankton net. Microscopic enumeration was employed to determine abundance of rotifers and microcrustaceans. Dredging was conducted within Banana Lake between August, 1990 and August, 1991. During and after dredging, all species of zooplankters had decreasing trends except for* Asplanchna *sp., a predatory rotifer. Most species started to decline in January, 1991 and by October, 1991 all of the cladocerans and copepods had disappeared. Recovery had begun by March, 1992.*

THE objective of this study was to monitor the zooplankton community; its composition, density, and diversity; as part of the evaluation for the Banana Lake restoration project. Zooplankton were collected from Banana Lake between January, 1990 and March, 1992; prior to, during and after hydraulic dredging. Only the rotifers and microcrustaceans were evaluated.

METHODS AND MATERIALS—*Description of study area*—Banana Lake is an 121 ha, shallow, hypereutrophic lake located approximately 5.6 km southeast of Lakeland, Florida. For nearly one-half a century this central Florida lake received sewage effluent from the City of Lakeland that generally exceeded 10 mgd prior to its abatement in May, 1987 (Bromwell and Carrier, 1991). Nutrients from the STP discharge resulted in the eutrophication of the lake which produced a flocculent organic sediment and a reduction in water depth. The average water depth of Banana Lake prior to its restoration was 0.8 m. Chlorophyll *a* values greater than 200 μg L^{-1} were common in all seasons and often exceeded 300 μg L^{-1} in autumn. Typical of most hypereutrophic lakes, Banana Lake had become an unusable and undesirable aquatic resource.

Restoration technique—Through extensive review and with the involvement of several State and Local agencies (Southwest Florida Water Management District, Peace River Basin Board, City of Lakeland, Polk County, Florida Game and Fresh Water Fish Commission), the Banana Lake Project became part of the Surface Water Improvement and Management (SWIM) program in 1989. The restoration technique to reverse the eutrophication process was the removal of nutrient laden lake sediment by hydraulic dredging (Bromwell and Carrier, 1991). Dredging began in August, 1990 and was terminated in August, 1991. Lake sediment was pumped into a lowland located on the northern side of Banana Lake. The returning water was passed through a silt curtain, then through a clarification pond and finally into a wetland prior to its re-entry into Banana Lake. It was estimated that nearly 572,000 m^3 of sediment were removed from the lake during the 12 months of dredging. This resulted in an increase in the mean depth from 0.8 m to 1.4 m and a doubling of lake volume from 728,000 m^3 in 1987 to 1,490,000 m^3 in 1991 (Bromwell and Carrier, 1991).

Sampling method and design—The sampling of the zooplankton community in Banana Lake was conducted utilizing a random sampling design where sample stations, represented by grid squares, were chosen randomly from a grid map. Eight stations were sampled from Banana Lake per month over a 2-year, 3-month period, January, 1990–March, 1992. Zooplankters were collected using an 8.1 L Kemmerer water sampler. Four sample collections per station were strained through a #20 nylon bolting cloth net (mesh size = 75 μ) and concentrated in a Wisconsin plankton bucket attached to the cod-end. The zooplankton samples were preserved using 3–5% formalin with a 0.04% rose bengal solution added as a staining agent. Samples were retaken if sediment contamination was present. The zooplankton collections were made by personnel from the City of Lakeland. After each sample had been placed into a round bottom flask, 1 mL aliquots were taken with a Hensen-Stempel pipette, placed into a 1 mL Sedgwick-Rafter counting chamber and strip counted with a binocular compound microscope at 200 ×. Two aliquots were obtained from each sample to acquire a mean number of individuals per species. Ahlstrom (1934), Brooks (1957), Edmondson (1959), Harring and Myers (1922, 1924, 1926, 1928), Pennak (1953, 1978, 1989), and Voigt (1956) were used for identification. As zooplankters were encountered in the samples, they were 'keyed' into a computer spreadsheet to calculate abundance, monthly and annual means, and species diversity indices. Species diversity was determined using enumerated data (per station) in the calculation of the Shannon Index [Diversity = $-\Sigma(ni/N \log2)(ni/N)$, (Wilhm and Dorris, 1968), where ni = the number of individuals of the ith species and N = the total number of individuals of all species]. The Simpson Index ($SI = \Sigma(ni(ni-1)/N(N-1))$, where ni = the number of individuals of the ith species and N = the total number of individuals of all species) was used to determine a dominance index for the community (Simpson, 1949). Equitability (E = Diversity divided by the highest possible Diversity given the number of species and the number of individuals found in the sample) was calculated to provide an index for evenness (Pielou, 1966).

RESULTS AND DISCUSSION—Thirteen species of rotifers, 7 species of cladocerans and 5 species of copepods (1 calanoid and 4 cyclopid) for a total of 25 zooplankton species, were collected from Banana lake during 1990 (Table 1). While not all species were found in every sample or during the same month, most were represented on a month by month basis giving rise to the annual mean number of 21 species L^{-1} for 1990. The annual mean number of rotifer species L^{-1} found in 1990 was 10; this number was not substantially higher than the 7 cladoceran species L^{-1} and 4 copepod species L^{-1} obtained. On an annual basis, the most abundant rotifers were *Asplanchna* sp; a predatory species that consumes rotifers and microcrustaceans (18.4% of the annual mean abundance) and a bdelloid rotifer of unknown species (23.5% of the annual mean abundance). Each of the other rotifer species was represented by less than 15% of the overall annual mean abundance for all the rotifers. Two species of cladocerans shared the dominant role for that group, *Bosmina longirostris* and *Eubosmina longispina*; each representing 25.4% of the annual mean abundance. The third most abundant cladoceran was *Daphnia ambigua* representing 13.6% of the annual mean

TABLE 1. Mean zooplankton abundance by species in Banana Lake, 1990, 1991, and January–March, 1992.

Species of Zooplankton	Numbers L^{-1} 1990	1991	Jan.–Mar., 1992
ROTIFERS			
Asplanchna sp.	104	61	25
Bdelloid species	133	52	22
Brachionus bidentata	35	28	7
Brachionus havanaensis	31	29	17
Brachionus quadridentata	35	22	16
Filina opoliensis	58	28	0
Keratella cochlearis	40	28	13
Keratella earlinae	80	30	15
Lecane luna	11	31	0
Monostyla sp.	2	1	0
Polyarthra sp.	29	27	10
Testudinella patina	6	25	0
Unknown	1	1	0
Total rotifers	565	363	125
CLADOCERANS			
Alona quadrangularis	39	24	0
Bosmina longirostris	150	38	16
Ceriodaphnia reticulata	64	25	0
Chydorus sphaericus	40	23	0
Daphnia ambigua	80	32	14
Diaphanosoma brachyurum	66	35	0
Eubosmina longispina	150	50	18
Total cladocerans	589	227	48
COPEPODS			
Diaptomus dorsalis	59	29	11
Cyclops varicans	21	26	0
Mesocyclops edax	24	24	5
Paracyclops fimbriatus	35	23	0
Tropocyclops parsinus	25	27	0
Total copepods	164	129	16
GRAND TOTAL	1318	719	189

abundance followed by *Diaphanosoma brachyurum* which comprised 11.2%. *Diaptomus dorsalis* led the copepods in abundance with 36% of the annual mean copepod abundance followed by *Paracyclops fimbriatus* which made up 21.3%. A conspicuous absence in the calanoid copepod 'line up' was *Diaptomus floridanus* and *Diaptomus mississippiensis,* two fairly common diaptomids found in Florida's freshwater lakes. According to Elmore (1983) *D. dorsalis* is usually the sole diaptomid in eutrophic and hypereutrophic lakes, while *D. floridanus* and *D. mississippiensis* usually co-occur in oligotrophic and mesotrophic lakes in Florida.

No additional zooplankton species were encountered during 1991 or during January–March, 1992 (Table 1). In conjunction, only small differences were found between 1990 and 1991 for the mean numbers of species L^{-1} (21 for 1990 and 24 for 1991). During 1991, all species with the exception of *Asplanchna sp.*, had declining trends, being quite dissimilar to those previously observed in 1990. With only one exception (*Tropocyclops prasinus*), all species started to decline in abundance during January, 1991. By August, 1991, the month that sediment dredging was discontinued, several species had disappeared; these were *Filina opolinesis, Monostyla sp., Testudinella patina, Chydorus sphaericus, Cyclops varicans,* and *Tropocyclops prasinus.* Additional species disappeared in September, 1991: *Alona quadrangularis, Bosmina longirostris,* and *Ceriodaphnia reticulata.* By October, 1991; *Brachionus quadridentata, Keratella earlinae, Lecane luna, Polyarthra sp., Ceriodaphnia reticulata, Daphnia ambigua, Diaphanosoma brachyurum, Eubosmina longispina, Diaptomus dorsalis,* and *Paracyclops fimbriatus* had also disappeared. Of the eight species of rotifers that remained, the abundance of *Asplanchna sp.,* appeared to peak in 1991, reaching 179 individuals L^{-1}. While all 25 species identified in Banana Lake were found in June and July, 1991; only 8 species remained by December, 1991. Relative abundances fell from 799 individuals L^{-1} in June, 1991 to 63 individuals L^{-1} in December, 1991. The zooplankton did not begin to reoccur until February, 1992 (Fig. 1). By March, 1992, the last month samples were taken, the mean number of species L^{-1} had increased to 13 and the mean number of individuals L^{-1} had risen to 286. Eight species of rotifers, 3 species of cladocerans and 2 species of copepods were found.

One can only speculate as to the cause for the decline in the zooplankton community in Banana Lake during 1991. Undoubtably, it was associated, either directly or indirectly, with the removal of sediment by the hydraulic dredging process which was conducted between August, 1990 and August, 1991. Since the effect of the dredging did not appear to be species specific, but rather eliminated all species of microcrustaceans and most of the rotifers, a best guess would be that the demise of the zooplankton species was associated with a large algae bloom that occurred in Banana Lake during January and February, 1991, approximately midway into the dredging operation. Chlorophyll*a* for January and February, 1991 was 534.5 and 404.6 $\mu g\ L^{-1}$, respectively; (Polk County Water Resources Laboratory). Heavy algae blooms have been known to eliminate zooplankters. Dunn (1970) reported a thick bloom of *Anabaenopsis philippinensis* that completely eliminated all planktonic rotifers and crustacean in a tropical pond in Uganda and suggested that it was the decay of the algae rather than the presence of the algae that produced the toxic effect. Of all the algae that produce toxic substances, *Microcystis sp.* is probably the best known; its peptide toxin causes illness and/or death to aquatic organisms and often affects wild and domestic animals (Penaloza et al., 1990). In their discussion of the toxic activity of soluble peptide toxin from *Microcystis,* Penaloza and other co-workers (1990) produced sev-

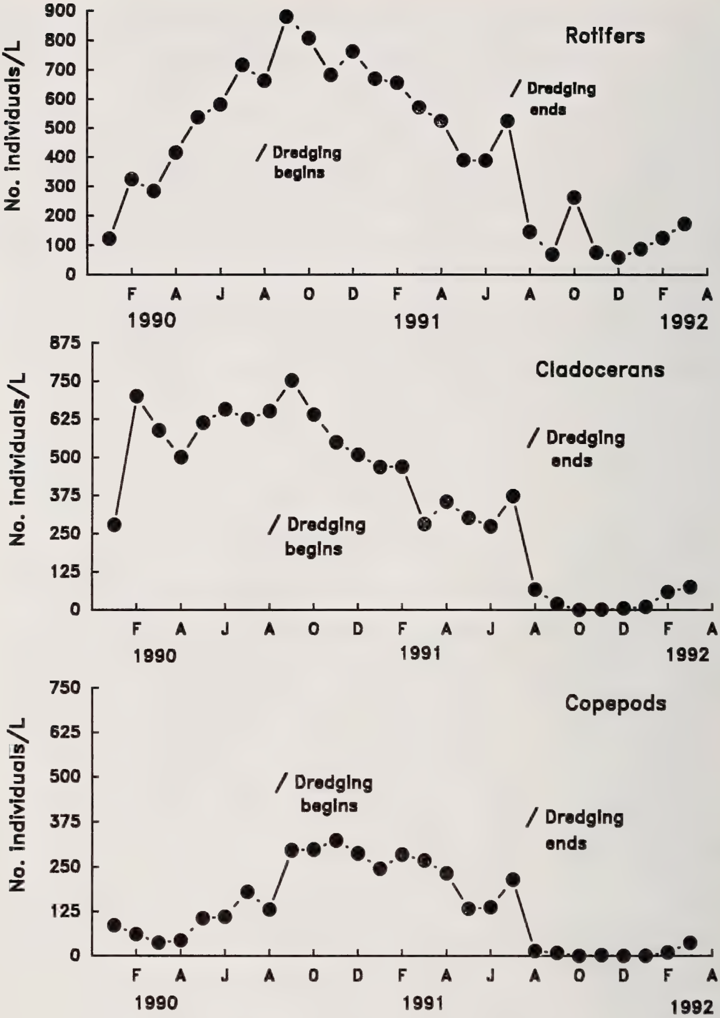


FIG. 1. Monthly mean abundance for rotifers, cladocerans and copepods in Banana Lake, January, 1990–March, 1992.

eral citations where blooms of this species in eutrophic lakes killed crustacean zooplankton.

Cladocerans rather than rotifers tended to be the most abundant zooplankton group in Banana Lake during 1990. The annual mean abundance for rotifers was 565 individuals L^{-1}, cladocerans had 589 individuals L^{-1} and copepods had 164 individuals L^{-1}. The annual mean number of individuals L^{-1} species^{-1} was largest for the cladocerans with 88. There were 58 individuals L^{-1} species^{-1} for rotifers and 41 individuals L^{-1} species^{-1} for the copepods. The calanoid species (*Diaptomus dorsalis*) out numbered the combined species of cyclopoid (59 vs. 31 individuals L^{-1} species^{-1}).

TABLE 2. Mean species diversity indices for zooplankton in Banana Lake for 1990, 1991, and January–March, 1992.

Parameters	1990	1991	Jan.–Mar., 1992
Mean No. species L^{-1}	21	24	10
Mean No. individuals L^{-1}	1318	853	192
Mean No. individuals sp^{-1}	63	36	18
Shannon Index for diversity	3.98	3.63	3.20
Simpson Index	0.13	0.13	0.11
Equitability Index	0.94	0.94	0.97

Rotifers comprised 50% of the zooplankton in 1991, compared to 43% of the zooplankton in 1990. Cladocerans became less abundant, making up 32% of the zooplankton in 1991; they comprised 45% of the zooplankton in 1990. Copepods increased by 6% in abundance between 1990 (12%) and 1991 (18%). Numbers of species of zooplankters tended to remain constant over the 12 month period of 1990. Abundance increased to a peak level in September, 1990 (1,929 individuals L^{-1}) before declining, Figure 1. January had the lowest monthly mean abundance with 488 individuals L^{-1} for 1990. The annual mean number of zooplankters in Banana Lake for 1990 was 1,318 individuals L^{-1}. Generally, zooplankter abundances tended to be high in Banana lake relative to other less eutrophic lake systems (Billets and Osborne, 1985). What Banana Lake lacked in species, it gained in numbers of individuals per species. The general limitation of rotifer species was probably the result of the eutrophication of Banana lake and low numbers of rotifers have been observed in other hyper-eutrophic Florida lakes as well. Lake Apopka, studied by this author in 1973–74, contained only 10 species of rotifers. On the other hand, some investigators have suggested that eutrophic lakes contain a greater number of rotifers than oligotrophic or mesotrophic lakes (Blancher, 1984, Elmore et al., 1984).

The Shannon Index for species diversity is a measure of community structure related to (1) the number of species present and (2) the relative distribution of individuals within those species. Of these two factors, the number of species plays the dominate role in determining the value of the index than does the relative distribution of individuals. Consequently, finding a new species has a greater effect on the value of the species diversity index than does having the abundance change for a given species. It is for this reason that the Shannon Index has been critized as being insensitive to community changes. In Banana Lake, the number of species did not vary little over the course of 1990; the number of species per month varied only between 17 (March) and 23 (December). Since most of the species tended to have similar abundances, the species diversity index (Shannon Index for species diversity) remained fairly constant during that year. Monthly mean values for the Shannon Index ranged from 3.28 in February, 1990 to 4.43 in December, 1990, Table 2. The annual mean for 1990 was 3.98. Species diversity values during 1991 were similar to those reported for the latter portion of 1990; generally approaching 4.5. With the decline in the number of zooplankton species and their abundance post-August, 1991; species diversity declined to a low of 1.27 in October, 1991. By December, 1991 the Shannon Index was on the rise (1.99) and by March, 1992 it had reached 3.59. The species diversity values for Banana lake are considered relatively high for a zooplankton community. One of the first publications giving Shannon Index values for a zooplankton community was published for Keystone Reservoir, Oklahoma by Kochsiek and co-workers (1971). They reported values for the Shannon Index of 2.39 to 2.61 for this hardwater reservoir. Richard and co-workers (1984) reported annual mean values for the Shannon Index for four hydrilla infested lakes in Central Florida ranged from 1.62 to 2.16. Annual species diversity for the zooplankton in a clear, acidic lake in the lower central highlands of Central Florida (Spring Lake) for 1973–74, 1974–75, and 1975–76 were 3.41, 3.30 and 3.68, respectively (Billets and Osborne, 1985). Similarily, Fry and Osborne (1980) reported Shannon indices for three experimental ponds on the campus of the University of Central Florida that ranged from 2.51 to 2.83. The relatively high species diversity for Banana Lake in contrast to other Florida lake studies was probably due to the consistency of species numbers and the similarity of the abundances per species.

The Simpson Index (SI), a measure of the dominance of one or more species over the remaining species, has a value between 0 and 1; 0 being a community that has the same number of individuals for each species and 1 for a community that has all its individuals belonging to a single species and only one individual for each remaining species. The Simpson Index for the zooplankton community in Banana Lake was quite small, monthly mean values ranged from 0.05 to 0.16 (Table 2). This indicates that the distribution of individuals among the species in Banana Lake were similar, with no truly dominate species being represented. The annual mean SI for 1990 was 0.09, it was 0.13 for 1991. The Equitability Index (E) is an index of similarity or evenness of individuals distributed throughout the species. Basically, it is the reciprocal of the Simpson Index, but ranges from 0 (all individuals belong to the same species with all remaining species represented by one individual) to 1 (all species have the same number of individuals). The monthly mean values for E ranged from 0.77 to 0.98 in 1990; the annual mean for 1990 was 0.91 and for 1991 it was 0.94.

LITERATURE CITED

AHLSTROM, E. H. 1934. Rotatoria of Florida. Trans. Am. Microsc. Soc. 53:251–256.

BILLETS, B. D. AND J. A. OSBORNE. 1985. Zooplankton abundance and diversity in Spring Lake, Florida. Florida Scient. 48:1129–139.

BLANCHER, E.C. 1984. Zooplankton trophic state relationships in some north and central Florida lakes. Hydrobiol. 109:251–263.

BROMWELL AND CARRIER, INC. 1991. Banana Lake Dredging Project. Final Report submitted to the Polk County Water Resources, Bartow, Florida. 25 p. Unpublished Report.

BROOKS, J. L. 1957. The systematics of North American *Daphnia*. Mem. Conn. Acad. Arts Sci. 13:1–180.

DUNN, I. G. 1970. Recovery of a tropical pond zooplankton community after destruction by algal bloom. Limnol. Oceanogr. 15:373–379.

EDMONDSON, W. T. (ed.) 1959. H. B. WARD AND G. C. WHIPPLE'S Fresh-Water Biology. 2nd ed., John Wiley & Sons, New York, NY. 1248 pp.

ELMORE, J. L. 1983. Factors influencing *Diaptomus* distributions: An experimental study in subtropical Florida. Limnol. Oceanogr. 28:522–532.

———, B. C. COWELL, AND D. S. VODOPICH. 1984. Biological communities of three subtropical Florida lakes of different trophic character. Arch. Hydrobiol. 100:455–478.

FRY, D. L. AND J. A. OSBORNE. 1980. Zooplankton abundance and diversity in Central Florida grass carp ponds. Hydrobiol. 68:145–155.

HARRING, H. K. AND F. J. MYERS. 1922. The rotifer fauna of Wisconsin. Trans. Wis. Acad. Sci. Arts. Lett. 20:553–662.

———. 1924. The rotifer fauna of Wisconsin. II. A revision of the notommatid rotifers, exclusive of the Dicranophorinae Trans. Wis. Acad. Sci. Arts. Lett. 21:415–549.

———. 1926. The rotifer fauna of Wisconsin. III. A revision of the genera *Lecane* and *Monostyla*. Trans. Wis. Acad. Sci. Arts. Lett. 22:15–423.

———. 1928. The rotifer fauna of Wisconsin. IV. The Dicranophorinae. Trans. Wis. Acad. Sci. Arts. Lett. 23:667–808.

KOCHSIEK, K. A., J. L. WILHM, AND R. MORRISON. 1971. Species diversity of net zooplankton and physicochemical conditions in Keystone reservoir, Oklahoma. J. Ecol. 52:1119–1125.

PENALOZA, R., M. ROJAS, I. VALA, AND F. ZAMBRANO. 1990. Toxicity of a soluble peptide from *Microcystis* sp. to zooplankton and fish. Freshwa. Biol. 24:233–240.

PENNAK, R. W. 1953. Fresh-water Invertebrates of the United States., 1st ed., Ronald Press Co., New York, NY, 769 pp.

———. 1978. Fresh-water Invertebrates of the United States., 2nd ed., John Riley & Sons, New York, NY, 803 pp.

———. 1989. Fresh-water Invertebrates of the United States., 3rd ed., John Wiley & Sons, Inc., New York, NY, 628 pp.

PIELOU, E. C. 1966. The measurement of diversity in different types of biological collections. J. Theo. Biol. 13:131–144.

RICHARD, D. I., J. W. SMALL, JR., AND J. A. OSBORNE. 1984. Phytoplankton responses to reduction and elimination of submersed vegetation by herbicides and grass carp in four Florida lakes. Aquat. Bot. 20:307–319.

SIMPSON, E. H. 1949. Measurement of diversity. Nature (London). 163:638.

VOIGT, M. 1956. Rotatoria. Die Radertiere Mi-teleuropas, Gebruder Borntraeger, Berlin. 508 pp.

WILHM, J. L. AND T. C. DORRIS. 1968. Biological parameters of water quality. Biosci. 18:477–481.

Florida Scient. 60(2): 104–111. 1997
Accepted: October 11, 1996.

PREDATION ON AN EVENING BAT (*NYCTICEIUS* SP.) BY SQUIRREL MONKEYS (*SAIMIRI SCIUREUS*) IN SOUTH FLORIDA

LINDA L. TAYLOR(1) AND SHAWN M. LEHMAN(2)

(1)Department of Anthropology, University of Miami, P.O. Box 248106,
Coral Gables, FL 33124-2005
(2)Department of Anthropology, Washington University, One Brookings Drive,
Campus Box 1114, St. Louis, MO 63130

ABSTRACT: *In this paper we report a case of predation by squirrel monkeys (*Saimiri sciureus*) on a solitary-roosting evening bat (*Nycticeius *sp., Veristomillidae). The monkeys, translocated to South Florida from South America, now inhabit a 35 acre home range on which they have been established for decades. The monkeys were successful in obtaining bat prey despite the presence of potential competitors for that prey, e.g., raccoons. Predation upon bats is very rare among nonhuman primates. This report is the only confirmed instance of bat predation by nonhuman primates living in Florida, and the only report for this species. Only squirrel monkeys of the closely related *S. oerstedii *species have been reported to be regular predators on bats in Costa Rica. The monkeys we observed have successfully adapted their foraging behavior to this unique South Florida habitat despite their having originated elsewhere in the Neotropics.*

SQUIRREL monkeys (*Saimiri* sp.) are common in South America and are found across a considerable geographical area (Hershkovitz, 1977). This small monkey, approximately 500–1100 grams for adult animals (Baldwin, 1985), has been imported frequently into the United States during the last century for the pet/zoo trade and biomedical consumers (Mittermeier et al., 1994).

Monkeys have been imported into Florida for many years and are still offered for sale in newspapers and some pet shops. Intentional releases, and/or accidental escapes, of several species have led to the establishment of populations of free-ranging monkeys within the state, e.g., rhesus macaques (*Macaca mulatta*) on Key Lois (e.g., Oster, 1975; Lehman et al., 1994) and vervet monkeys (*Cercopithecus aethiops*) in Westlake Park, Dania (Hyler, 1995). One such population is a group of squirrel monkeys that ranges freely on a 35-acre site in urban Southeastern Florida.

In the wild, squirrel monkeys have an eclectic diet, composed primarily of insects, fruits, flowers, and, vertebrate and invertebrate animal prey (e.g., Boinski, 1987; 1988). The Florida population exhibits similar overall dietary patterns (Leon and Taylor, 1996), although some of the animal and plant species exploited by the monkeys differ due to differences in habitat. The object of this paper is to report an instance of bat predation by squirrel monkeys born in South Florida and to document how their behavior compares with that observed in the wild.

METHODS—*Study site*—The monkeys range on a 35 acre site, the Bartlett Estate. The site is listed in the National Register of Historic places and has been described elsewhere (e.g., Carr, 1985; Wheeler, 1990). The site supports five distinct habitats, including native plants in addition to large areas of disturbed habitat dominated by nonnative, cultivated plant species.

Study animals—A single group of squirrel monkeys (*Saimiri sciureus*) ranges across the study site. During observations the group numbered 39 individuals, including 5 infants born during the fall of 1995. The monkeys are tentatively identified as the Brazilian subspecies, *S. s. macrodon* by R.W. Cooper (1995) (c.f. *Saimiri sciureus sciureus,* Leticia, in Rosenblum and Coe, 1985). The monkeys constitute one large, spatially-dispersed group, with females and their dependent young forming the central core of the social group. Adult males and juveniles of both sexes are usually found on the periphery of the group, or in play or foraging subgroups.

Data collection—We used scan sampling data collection techniques to record behavior of the group members at five-minute intervals. Feeding resources were documented during these scans by noting species, part eaten, and location on site.

RESULTS—It remains unclear as to exactly when and how the monkeys came to be on the estate. It has been reported (e.g., Wheeler, 1990) that the founding members of this population were former pets accidentally- or intentionally-released onto the site around World War II. The monkeys have been present on the site for several decades. Given that the average lifespan of this species is 20 years or less in captivity (Napier and Napier, 1985), it is certain that all monkeys in the study group were born in Florida. It is possible that wild-born monkeys were incorporated into the group since it became established at the site. However, we could not find any data to support that possibility.

The monkeys range freely across the entire 35 acre site, and sometimes beyond it (Leon and Taylor, 1996). They are often fed by tourists along the borders of the estate. When on the estate, they forage on native vegetation (e.g., seagrape [*Cocobola uvifera*]), introduced plant species (e.g., guava [*Psidium* sp.]), and small vertebrates like anole lizards and geckos. They spend considerable time foraging for insects and other prey in the shaggy bark of melaleuca trees and for spittle bugs in the Australian pine needles. During foraging, the monkeys often explore and manipulate the dead fronds (or beards) surrounding the trunks of sabal palms. This behavior consists of lifting up the beards and inspecting the undersides. When in the palms, the monkeys generate a considerable amount of falling debris, which calls attention to their location and activities.

Data were being collected in the morning hours of September 22, 1994, as the monkeys foraged in the palm beards. The monkeys began emitting high-pitched vocalizations while under the fronds. At least five adults congregated in one sabal palm. We observed several monkeys fall as a group from the tree some 4 meters to the forest floor, as a small, dark-colored bat flew out of the group. It was evident from its ragged flight that the bat had already been severely injured.

Eleven monkeys descended from the palm and mobbed the bat, tearing it into two large pieces. One adult male and an adult female with a nursing infant captured the two largest pieces. Both adults then moved to separate higher perches and began eating the body segments, holding the carcass by the shoulder joint (Figure 1).

The main portions of the bat's trunk were consumed avidly. One young animal, who managed to grab the intestines smelled them, took one bite, and then held the guts at arm's length and dropped the entire portion to the ground while shaking its head violently. The wings were not discarded until such time as most of the body had been consumed, bones and all. The wings were mouthed and dropped. Younger individuals grabbed the pieces of wing as they fell, running to distant perches. All leathery wing segments were tasted and immediately discarded. No portion of the carcass that fell to the ground was retrieved by any of the monkeys. The entire capture and consumption took less than 15 minutes.

The bat was tentatively identified as an evening bat (*Nycticeius* sp.), a member of the bat family Veristomillidae (Fleming, 1995). These bats range globally in tropic and temperate zones.

DISCUSSION—The study population has successfully established a foraging pattern that has permitted the group to increase from a pair or a few pairs, and now to maintain its number. Their dietary patterns resemble the patterns documented for wild squirrel monkeys in terms of general content and proportions thereof (e.g., Boinski, 1987, 1988; Thorington, 1968). In addition, they have discovered bats as prey, in much the same manner as have their wild counterparts in Costa Rica (Boinski and Timm, 1985).

For most mammalian predators, a lone bat is a small meal. Therefore, many predators strike when the bats appear in large numbers, such as leaving or returning to roost sites, as a means of capturing several bats in a single outing (Fenton, 1992). The bat prey in this case was a solitary individual. The small body size of the squirrel monkeys, in comparison to larger predators, makes the bat a very substantial food item for the monkeys.

The unique habitat of this Florida population may also contribute to their success in bat predation in a surprising manner. Tuttle and Stevenson (1982), writing about predation on bats, state that "Most would-be predators are likely frightened away by human activity . . ."(p. 136). The monkeys we observed are entirely habituated to humans and unperturbed by their presence. Potential competitors for the bats (e.g. owls and raccoons) usually move away from any human activity at the site or are active at night. Thus, the behavior of potential competitors for bat prey may actually have enhanced the success of the monkeys' predation efforts.

The question remains as to whether or not the monkeys were intention-

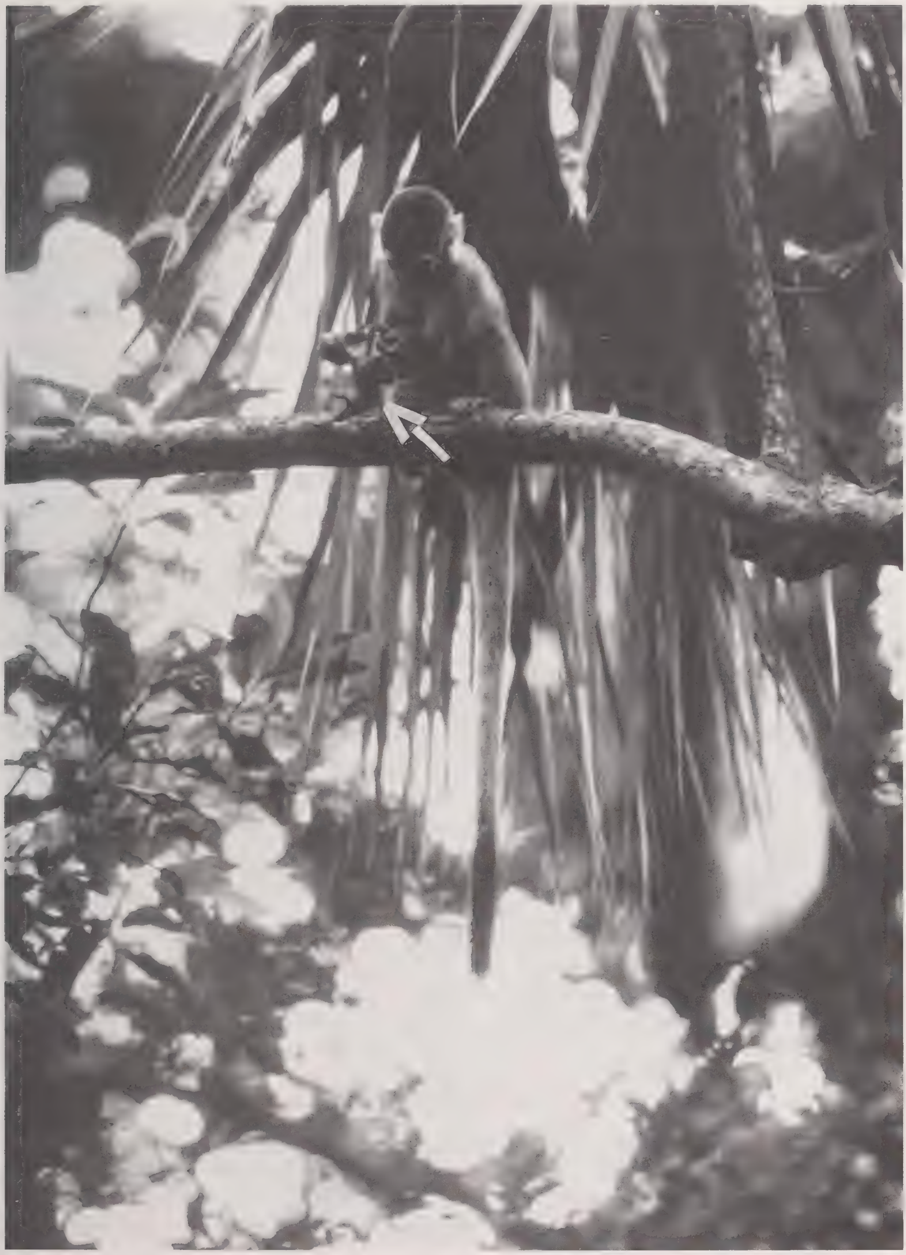


FIG. 1. A young male squirrel monkey holds a portion of an evening bat carcass (arrow) by the shoulder and examines it prior to consumption.

ally seeking bats. A variety of lizards and insects also inhabit the beards of sabal palms, therefore, we cannot state conclusively that monkeys were hunting through the fronds exclusively for bats. The monkeys continue to forage routinely through the dead palm fronds in the same specific area in the same manner, but have not been observed to take another bat. Large numbers of bats appear over the buildings each evening, offering evidence that bats are still roosting on the site.

Predation by primates on bats is a rarely reported phenomenon in general; invertebrates are the usual animal prey for most species (Butynski, 1982). Boinski and Timm (1985) report that outside of their study, there had been only one "confirmed" report of bat predation by a primate (p. 125). The predator in that case was a potto (*Perodicticus potto)* a nocturnal prosimian species. Thus, predation upon bats is a very rare occurrence for the entire range of nonhuman primate taxa, even in settings in which potential bat prey exist. It is likely, therefore, that bat predation is a rare occurrence in this population, although bats may constitute a significant resource that the squirrel monkeys are able to exploit effectively.

None of the other monkey populations in Florida have been reported to prey on bats, e.g., rhesus macaques in the Florida Keys (Lessnau, 1995). Squirrel monkeys of the same species also range freely at Monkey Jungle in Goulds, Florida (DuMond, 1968). Although Goulds offers a very similar habitat, the squirrel monkeys there have not been observed to prey upon bats (Evans, 1995). Reports of predation on bats by wild squirrel monkeys are limited to the *S. oesterdii* species in Costa Rica (Boinski and Timm, 1985). Therefore, the population we observed is the only population of monkeys in Florida, and the only population of the *S. sciureus* species, known to prey on bats. Despite having originated in the Neotropics, the study group has successfully adapted its foraging behavior to the unique resources of a South Florida habitat.

ACKNOWLEDGMENTS—We thank Robert Kauth, Lisa Bova, and Susan Parker and the entire staff of the Bonnet House. C. Harper Hellams was our excellent photographer.

LITERATURE CITED

BALDWIN, J. D. 1985. The behavior of squirrel monkeys (*Saimiri*) in natural environments. Pp. 35–53. *In*: ROSENBLUM, L. AND C. L. COE (eds.). The Handbook of Squirrel Monkey Research. Plenum Press, New York, NY.

BOINSKI, S. 1987. Habitat use by squirrel monkeys (*Saimiri oesterdii*) in Costa Rica. Folia Primatol. 49:151–167.

———. 1988. Sex differences in the foraging behavior of squirrel monkeys in a seasonal habitat. Behav. Ecol. Sociobiol. 23:177–186.

——— AND R. T. TIMM. 1985. Predation by squirrel monkeys and double tooth kites on tent-making bats. Am. J. Primatol. 9:121–127.

BUTYNSKI, T. M. 1982. Vertebrate predation by primates: a review of hunting patterns and prey. J. Human Evol. 11:421–430.

CARR, R. S. 1985. An archaeological survey of the Bartlett Estate, Broward, County, Florida.

A typescript of a file with the Florida Division of Archives, History and Records Management, Tallahassee, FL.

COOPER, R. W. 1995. Personal communication. Division of Veterinary Resources, University of Miami School of Medicine, Miami, FL.

DUMOND, F. V. 1968. The squirrel monkey in a seminatural environment. Pp. 88–144. *In*: ROSENBLUM, L. AND R. W. COOPER (eds.). The Squirrel Monkey. Academic Press, New York, NY.

EVANS, S. 1995. Personal communication. The Dumond Conservancy for Primates in Tropical Forests. Goulds, FL

FENTON, M. M. 1992. Bats. Facts on File Inc., New York, NY.

FLEMING, T. 1995. Personal communication. Department of Biology, University of Miami, Coral Gables, FL.

HERSHKOVITZ, P. 1977. Living New World Monkeys (Platyrrhini) with an Introduction to the Primates, Vol. 1. University of Chicago Press, Chicago, IL.

HYLER, W. R. 1995. Vervet monkeys in the mangrove ecosystems of southeastern Florida: Preliminary census and ecological data. Florida Scien. 58(1): 38–43.

KUNZ, T. H. 1982. Roosting Ecology, Pp. 1–56. *In*: The Ecology of Bats. KUNZ, T. H. (ed.). Plenum Press, New York, NY.

LEHMAN, S. M., L. L. TAYLOR, AND S. P. EASLEY. 1994. Climate and reproductive seasonality in two free-ranging island populations of rhesus macaques (*Macaca mulatta*). Int. J. Primatol. 15(1):115–128.

LEON, B. S. AND L. L. TAYLOR. 1996. Behavioral Ecology of an urban troop of squirrel monkeys (*Saimiri sciureus*). Abstracts of the 16th Congress of the International Primatological Society, University of Wisconsin, Madison, WI.

LESSNAU, R. G. 1995. Personal Communication. New York Zoological Society, St. Catherine's Island, GA.

MITTERMEIER, R. A., W. R. KONSTANT, AND R. B. MAST. 1994. Use of Neotropical and Malagasy primate species in biomedical research. Amer. J. Primatol. 34:73–80.

NAPIER, J. R. AND P. H. NAPIER. 1985 The Natural History of the Primates. MIT Press, Cambridge, MA.

OSTER, H. L. 1975. Establishment of a free-ranging rhesus monkey breeding colony on Key Lois Island, Florida. Lab. Anim. Notebooks 6:107–117.

ROSENBLUM, L. AND C. L. COE. 1985. Preface, Pp. vii–x. *In*: ROSENBLUM, L. AND C. L. COE (eds.). The Handbook of Squirrel Monkey Research. Plenum Press, New York, NY.

THORINGTON, R. W. 1968. Observations of squirrel monkeys in a Colombian forest. Pp. 69–84. *In*: ROSENBLUM, L. AND R. W. COOPER (eds.). The Squirrel Monkey. Academic Press, New York, NY.

TUTTLE, M. D., AND D. STEVENSON. 1982. Growth and survival of bats. Pp. 105–150. *In*: The Ecology of Bats, KUNZ T. H. (ed.). Plenum Press, New York, NY.

WHEELER, R. J. 1990. Behavioral characteristics of squirrel monkeys at the Bartlett Estate, Ft. Lauderdale. Florida Scient. 53(4):312–317.

Florida Scient. 60(2): 112–117. 1997
Accepted: October 11, 1996.

EFFECTS OF FIRE ON AN ENDANGERED FLORIDA PLANT, *DEERINGOTHAMNUS RUGELII*

Joseph H. Helkowski and Eliane M. Norman

Department of Biology, Stetson University, DeLand, FL 32720

Abstract: *To determine if disturbance affected the growth and flowering of* Deeringothamnus rugelii, *twelve experimental blocks were selected in a pasture where this species is abundant, near New Symrna Beach. Each block consisted of three treatments. One plant was subjected to fire, another to clearing by clipping all above ground growth, and the third plant was an unmanipulated control. We monitored vegetative growth, floral, and fruit production for four months. Disturbance significantly enhanced vegetative and floral output. Fruits were also produced in the disturbed treatments while none developed in the controls. No differences were observed among the treatments the following year.*

Fire plays a number of roles in the flatwoods ecosystems of Florida, including reducing competition from hardwoods, creating soil conditions suitable for germination of seeds of some species, increasing soil nutrients, and stimulating recruitment of other species (Abrahamson and Hartnett, 1990). Since Florida has the highest number of electrical storms in this country (Chen and Gerber, 1990), it also has many species adapted to frequent burns caused by these lightning strikes. The pine flatwoods understories typically burn vigorously but at much lower intensities than more forested ecosystems leaving few unburned patches. Most species in these understories rapidly send up new shoots from underground stems or roots after a burn. Abrahamson (1980) has characterized many small shrubs in flatwoods as showing a "sit and wait" strategy. Using this strategy, the shrubs accumulate biomass underground, then react to fire by rapid growth and flower production.

The genus *Deeringothamnus* (Annonaceae) is endemic to Florida. Its two species were listed as "endangered" on 26 September 1986, under the Endangered Species Act (Coile, 1993). Rugel's pawpaw (*D. rugelii*) also known as the Yellow Squirrel Banana, the rarer of the two, is found only in a small area of Volusia County, Florida. In 1992, it was estimated that there were approximately 1,300 individuals in ten populations (Norman, 1993). This species is a dwarf shrub almost exclusively found in flatwoods communities with its most common associates *Pinus palustris* (longleaf pine), *Serenoa repens* (saw palmetto), *Lyonia lucida* (fetterbush), and *Aristida beyrichiana* (wire grass). Rugel's pawpaw produces new shoots and flowers in spring (mid-April–May), fruits in July or August and dies back to the ground in the fall, and remains dormant throughout the winter. In some cases a small amount of wood remains viable above ground, but branches on old wood rarely produce flowers. In a population of Rugel's pawpaw which has not been recently disturbed by fire or mowing, only 3–15% of plants flower in a particular year with a higher percentage found in the more open sites (Norman, unpublished data).

Increased human settlement has drastically altered fire regimes in Florida. Area burned per fire is limited by real estate development particularly in the case of lightning fires. As a result, forests burn less frequently now than they have in the past. Many pine flatwoods are becoming overgrown and nutrient-deficient due to reduced fire frequencies. Dense undergrowth, in turn, may cause the decline of many low-growing forbs and small shrubs.

Although Kral (1960) states that fire and other disturbances enhance flowering in the pawpaws (*Asimina* and *Deeringothamnus*), this effect has never been quantified. The present study attempts to determine the species' response to fire in a pasture, the only location available to us. We also wished to discover any differences in growth, flowering, and fruiting among plants that were undisturbed versus plants that were subjected to fire or clipping. Data obtained from this experiment may be useful in developing a management plan for the preservation of this rare and endangered species.

MATERIALS AND METHODS—The study site was a 2.5 ha privately managed pasture near New Smyrna Beach, Florida (29° 01′N latitude, 80°56′W longitude). This pasture was established approximately 25 years ago with the removal of saw palmetto and without the introduction of exotic grass species. For the first 3–4 years the pasture was grazed by horses which were subsequently replaced with a few cows. *Deeringothamnus rugelii* coexist in the study site with many species including *Asclepias pedicellata, Aristida beyrichiana* (wiregrass), *Asimina reticulata* (pawpaw), *Cuthbertia ornata* (roseling), *Galactia elliotti* (milk pea), *Lygodesmia aphylla* (roserush), *Phoebanthus grandiflorus, Pterocaulon pycnostachyum,* and *Pinus palustris* (longleaf pine). Understory shrubs such as *Serenoa repens* (saw palmetto), *Myrica cerifera* (wax myrtle), and *Ilex glabra* (gallberry), which are prevalent in surrounding flatwoods, are missing here leading to a high light intensity at ground level and presumably less interspecific competition among the ground-cover species. At the time of the study, there had been no fires at the study site for four years, but it was usually mowed twice a year, in July or August and again in October or November.

Thirty-six *D. rugelii* were located and marked with flags in a 0.6-ha section of the pasture on April 17, 1993. The field was surrounded by a 1.5 m wide fire break of turned-up soil. The thirty-six plants were then assigned to 12 experimental blocks with three specimens per block. Each member of a block was randomly assigned a different treatment. The date of the burn, April 17 1993, and the portion of the acreage which could be subjected to fire were dictated by the owner's wishes without interference in the experimental design.

The three treatments in each block included an unmanipulated plot, a burned plot, and a clipped plot. Burned plots were marked with a metal tag which survived burning. To ensure that the fire would completely burn the leaves and stems of the specimen, approximately 0.2 kg of pine-needle litter was piled around the specimen. The fuel burned rapidly and thoroughly, consuming all exposed parts of the specimen. In the clipped treatment, the specimens were cut at ground level and marked with a flag. The surrounding area (12-cm diameter) was cleared of vegetation. The unmanipulated plot served as a control.

We recorded the number of stems present for each individual at the beginning of the experiment. To monitor regrowth, flowering, and fruit production plants were observed on a

TABLE 1. The effect of treatment on the mean number and (±SE) of stems, change in stem number, flowers, and fruits produced per plant of *Deeringothamnus rugelii.* N = 12 for each treatment.

Plant parameter	Control	Clip	Burn
Mean number of stems ± SE	2.17 ± 0.20	2.91 ± 0.50	2.33 ± 0.38
Mean change in stem number ± SE	0.17 ± 0.17	1.41 ± 0.36*	0.42 ± 0.31
Mean number of flowers ± SE	1.17 ± 0.87	10.58 ± 4.01	17.08 ± 4.31*
Mean number of fruits ± SE	0.00 ± 0.00	0.16 ± 0.11	0.16 ± 0.11

* $P < 0.01$.

weekly basis after the start of the experiment until all flowers had been produced and all fruits had matured, i.e. from mid-April to the end of August. We only counted flowers that had their petals open far enough to expose stigmas and stamens. Since data were collected once a week and a flower of *D. rugelii* is in anthesis 3–5days (Norman, unpublished data), the total flower count was probably an underestimate but gives a general impression of reproductive effort. The change in stem number following burning or cutting was calculated for each plant as the starting number of stems minus the maximum number of stems observed during the experiment. Fruit production was summarized as mean mature fruit per plant for each treatment. The following year, flowers and fruits produced on the same plants was monitored on a biweekly basis from May to July.

Data analysis—Numbers of flowers and stems produced in 1993 in the 117-days of the experiment were analyzed using ANOVA for a randomized block experimental design. When an ANOVA was statistically significant ($P<0.05$), a Tukey test was performed to determine which of the treatment means differed significantly.

RESULTS—A larger number of stems, flowers, and fruits were produced in both experimental treatments than in the control (Table 1).

The mean number of stems was significantly different among treatments ($F=5.172$, $df=2$, $P=0.011$). Plants had a significantly greater number of stems in the clipped treatment (Tukey's test, $P=0.013$) than in the control plots. Burning, however, did not result in a number of stems that was significantly different from the control ($P=0.812$) or from the clipped treatment ($P=0.053$).

Flower production showed a significant difference among the treatments ($F=5.420$, $df=2$, $P=0.009$) allowing for the rejection of the null hypothesis. In the burn treatment, flower production was significantly greater (Tukey's test, $P=0.002$) than in control plots. The mean number of flowers produced in the clip treatment was not significantly different ($P=0.145$) from the control plots. Flower abundance between the two disturbed treatments was not significantly different ($P=0.386$). For undisturbed plants the mean time of flowering is mid-May while in the disturbed treatments it was delayed for one month (Fig. 1).

We did not perform ANOVA on the number of fruits produced due to a low sample size. Equal numbers of fruits were produced in both of the disturbed treatments. Only approximately 1% of flowers set mature fruits (Table 1). In 1994, the control group had 0.92 flowers per plant, while the

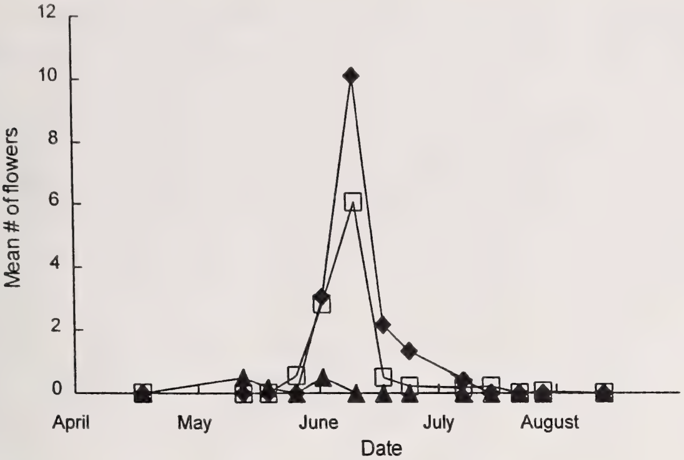


FIG. 1. Flower production in three treatments of *D. rugelii* in 1993. ▲ = control; ☐ = clipped; ◆ = burned.

burned and the clipped plants produced 1.8 flowers per plant. None of these plants set mature fruits.

DISCUSSION—As a natural governing force in plant communities, fire decreases interspecific competition among many herbaceous plant species (Christensen, 1977). Competition often restricts the size of individual plants (Wilson and Shay, 1990). However, Newman (1973; as cited in Wilson and Shay, 1990) mentions that the intensity of competition is often inversely correlated with light and soil resource availability. Increased light levels are apparent in a community after a reduction of litter and foliage. With increased light levels in the lower canopy of the plant community, herbaceous species will usually respond with increased growth.

The resprouting response of a plant is also commonly associated with increased nutrient availability (Matlack et al., 1993). Christensen (1977) found that concentrations of soil phosphate, calcium, magnesium, and potassium were increased following fire. Dudley and Lajtha (1993) found that mineral nitrogen leached into lower soil horizons following the first large rainstorms after a fire and was significantly depleted throughout the rooting zone. This would be beneficial to the normally suppressed herbaceous plants of a community. Slower growing species (hardwoods) use only a fraction of soil nutrients compared to herbaceous plants, giving these herbaceous species an edge in interspecific competition due to the more readily available soil nutrients (Herndon, 1988). To determine if soil nutrient availablity was a determining factor in the reproductive response of *D. rugelii* during this research, a further study would have to be conducted to learn the more percise correlation of nutrient availablity and *D. rugelii* response to this factor.

Aside from external factors affecting the resprouting of *D. rugelii,* internal physiological aspects also play a subsequent role in the regeneration of this species after disturbance. As noted by Matlack and co-workers (1993), resprouting is dependent on the death of the apical meristem. With the removal of apical dominance, an increase in the development of adventitious buds occurs due to the lowered levels of the hormone auxin (Wareing, 1969). Platt and co-workers (1988) discovered a release of dormant buds on several species of plants in a pine flatwoods forest after fire had destroyed their apical meristems. As shown in Table 1, disturbance by clipping and burning did result in increased stem production, but significantly so only in the clipped treatment. This result is puzzling; however, it is possible that the intensity of the fire caused a significant amount of meristematic tissue damage (Lloret and Lopez-Soria, 1993) and subsequently fewer branches developed.

Flowering is also stimulated by fire in many plant species (Baird, 1977, van der Moezel et al., 1987, as cited by Lamont and Runciman, 1993; Abrahamson, 1984). As shown in Table 1, a 15-fold increase in flowers was seen in burned *D. rugelii* versus the control. Species such as *Polygala rugelii, Palafoxia integrifolia, Galactia elliotii, Carphephorus paniculatus,* and *Serenoa repens* that increase flower production following fire, all store starch in large quantities in their tap roots (Abrahamson, 1984). *Deeringothamnus* likewise has a large tap root with abundant starch-storing tissue (Norman, personal observation). A combination of nutrients released by fire as well as stored energy in roots or stems seems to induce the increase in flower production. Other factors such as the release of ethylene gas may also act as a stimulant. Ethylene in the smoke from burning litter was a factor in inducing *Cyrtanthus ventricosus* from dormancy to flowering (Keely,1993).

Even though flower production rose in the disturbed plants, fruit production in both instances of disturbance was low (Table 1). It appears from other studies (Norman, unpublished data) that a very low number of pollen vectors severely limits fruit production in this species. From observations of flowering and fruiting abundance made on the same plants in 1994, it appears that the effect of the disturbance is not carried over beyond the immediate season. Thus, a fire in late winter or early spring every 2–3 years would probably be beneficial in maintaining populations of *D. rugelii.* This was the probable fire frequency found in long leaf pinelands in presettlement period (Mattoon, 1922). This timing would allow plants to come into flower during the normal blooming period, late April to early June, when they are more likely to attract pollinators. If fire is not feasible due to the population's location then periodic roller chopping is suggested as a management tool.

ACKNOWLEDGMENTS—This research was supported by US Fish and Wildlife Grant 14–16–0004–91–091 to E. M. Norman. We thank T. M. Farrell and P. G. May for assistance in statistical analysis and for editorial comments on the manuscript. We also thank L. Bishop and D. Spence for assistance in field work and data collection as well as the owners of the property where this research was conducted.

LITERATURE CITED

ABRAHAMSON, W. G. 1980. Demography and vegetative reproduction. Pp. 89–106. *In:* SOLBRIG, O. T. (ed.), Demography and Evolution of Plant Populations. Blackwell, Oxford.

———. 1984. Species responses to fire on the Florida Lake Wales ridge. Amer. J. Bot. 71(1): 35–43.

——— AND D. C. HARTNETT. 1990. Pine flatwoods and dry prairies, pp. 103–149. *In:* MYERS, R. L. AND J. J. EWEL (eds.), Ecosystems of Florida. University of Central Florida Press, Orlando, FL.

BAIRD, A. M. 1977. Regeneration after fire in King's Park, Perth, Western Australia. J. Roy. Soc. W. Austral. 60:1–22.

CHEN, E. AND J. F. GERBER. 1990. Climate. Pp. 11–24. *In*: MYERS, R. L. AND J. J. EWEL (eds.), Ecosystems of Florida. University of Central Florida Press, Orlando, FL.

COILE, N. C. 1993. Florida's endangered and threatened plants. Florida Dept. Agr. Consum. Serv., Div. Plt. Industry, Gainesville, FL.

CHRISTENSEN, N. L. 1977. Fire and soil-plant nutrient relations in a pine-wiregrass savanna on the coastal plain of North Carolina. Oecologia 31:27–44.

DUDLEY, J. AND D. LAJTHA. 1993. The effects of prescribed burning on nutrient availability and primary production in sandplain grasslands. Amer. Midl. Naturalist. 130:286–298.

HERNDON, A. 1988. Ecology and systematics of *Hypoxis sessilis* and *H. wrightii* (*Hypoxidaceae*) in southern Florida. Amer. J. Bot. 75(12):1803–1812.

KEELY, J. E. 1993. Smoked-induced flowering in the fire-lily *Cyrtanthus ventricosus*. S. Afr. J. Bot. 59(6):638.

KRAL, R. 1960. A revision of *Asimina* and *Deeringothamnus* (Annonaceae). Brittonia 12:233–278.

LAMONT, B. B. AND H. V. RUNCIMAN. 1993. Fire may stimulate flowering, branching, seed production and seedling establishment in two kangaroo paws (*Haemodoraceae*). J. Appl. Ecol. 30:256–264.

LLORET, F. AND L. LOPEZ-SORIA. 1993. Resprouting of *Erica mulitflora* after experimental fire treatments. J. Veg. Sci. 4:367–374.

MATLACK, G. R., D. J. GIBSON, AND R. E. GOOD. 1993. Regeneration of the shrub *Gaylussacia baccata* and associated species after low-intensity fire in an Atlantic coastal plain forest. Amer. J. Bot. 80(2):119–126.

MATTOON, W. R. 1922. Longleaf pine. Bull. No. 1061 USDA, Washington, DC.

NORMAN, E. M. 1993. Recovery plan for Rugel's pawpaw. U.S. Fish and Wildlife unpublished report. Contract 14-16-0004-91-091.

PLATT, W. J., G. W. EVANS, AND M. M. DAVIS. 1988. Effects of fire season on flowering of forbs and shrubs in longleaf pine forests. Oecologia. 76:353–363.

VAN DER MOEZEL, P. G., W. A. LONGERAGAN, AND D. T. BELL. 1987. Northern sandplain kwongan: regeneration following fire, juvenile period and flowering phenology. J. Roy. Soc. W. Austral. 69: 123–132.

WAREING, P. F. 1970. Growth and its co-ordination in trees. *In*: Physiology of Tree Crops. LUCKWILL, L. C. AND C. V. CUTTING (eds.). Academic Press, New York, NY.

WILSON, S. D. AND J. M. SHAY. 1990. Competition, fire, and nutrients in a mixed-grass prairie. Ecology 71(5):1959–1967.

Florida Scient. 60(2): 118–223. 1997
Accepted: October 16, 1996.

PRODUCTION OF WHEAT AND TRITICALE ON RECLAIMED PHOSPHATIC CLAY SETTLING AREAS IN CENTRAL FLORIDA

C. S. Gardner, *G. M. Prine, R. D. Barnett and E.C. French

Division of Agricultural Sciences, Florida A&M University, Tallahassee, Florida 32307

Abstract: *The Florida legislature has made it mandatory that lands disturbed for mining purposes should be reclaimed. Production of wheat [*Triticum aestivum *(L.) em. Thell] and triticale (×* Triticosecale *Wittmack) on phosphatic clay settling areas (> 48,000 ha) in south central Florida, could be economically beneficial to the state's livestock industry, while meeting the legislative land reclamation mandate. An experiment was conducted during the 1987 and 1988 growing seasons to study the development and yields of 'Florida 301' wheat and 'Florida 201' triticale, when planted early (mid October to November) and late (mid December to January) under Florida subtropical climatic conditions. The vegetative period averaged 15.5 and 5.5 days more for early planted wheat and triticale, respectively, compared to late planted treatments. Temperature during the growing season was approximately 3°C higher at initiation of reproductive developments for late planted treatments vs early planted treatments. This resulted in an average of 14.5 and 15 days reduction of the grain filling period (GFP) of late planted treatments for wheat and triticale, respectively. Under the subtropical conditions of south central Florida, late planting subjected both wheat and triticale crops to higher temperatures, especially during the period of reproductive development. This caused reduction in the duration of grain fill for these crops when planted late in the growing season. Grain yields for late planted treatments were reduced approximately 44 percent for wheat and 48 percent, for triticale compared to early planting for the 1988 growing season. The crops can be grown in the phosphatic clay environment although higher temperatures may reduce yields if planted late in the season. Better yields can be achieved by planting in late November or early December compared to planting in January.*

Temperate small grains in Florida are grown in the northern section of the state (Barnett et al., 1982), an environment representing the fringe of their area of adaptation (McCloud, 1982). The environment strongly impacts production of temperate small grain crops such as wheat and triticale (Wardlaw et al., 1980; Bruckner and Frohberg, 1987a). Being aware of this, plant breeders have used stability across environments, as well as performance within a specific environment, as adaptation criteria for crop selection (Fischer and Mauer, 1978; Wych et al., 1982; Bruckner and Frohberg, 1987a). Clarke and co-workers (1984) suggested that choice of crop should be environment-specific and that results from studies conducted in one environment should be confirmed in another.

The main environmental factors affecting the production of small grains are; temperature, solar radiation, moisture, soil nutrients, and pests and diseases including weeds (Linville et al., 1978; Laing and Fischer, 1977). Fischer (1985) stated that crops may experience different temperature regimes, depending on location and sowing date. Temperature is a major factor and influences the pace and development rate of crop growth (Weigand and Cuellar, 1981; McCloud, 1982). The post-anthesis or grain filling period (GFP), growth stage 10.5 to 11 (Large, 1954) is the most critical for grain yields.

---

* Corresponding Authors, Department of Agronomy, University of Florida, Gainesville, Florida 32611.

Grain filling period has been defined as the number of days from anthesis to physiological maturity, or the number of days from heading until chlorophyll disappearance from the glumes (Gebeyehou et al., 1982b; Knott and Gebeyehou, 1987). High temperatures at this stage will shorten the period, resulting in grain yield reduction (Sayed and Ghandorah, 1984; Fischer, 1985; Wardlaw et al., 1980). Sofield and co-workers (1977) found that temperature regimes of 15/10°C to 30/25°C day/night reduced wheat GFP from 60 to 20 days. Weigand and Cuellar (1981) reported that each degree rise in temperature (range 15.8 to 27.7°C) resulted in a three-day reduction of wheat GFP and concluded that temperatures above normal (15°C to 20°C) during the GFP may account for up to 25% yield reduction. These findings were similar to those of Warrington and co-workers (1977), who reported that high temperatures shortened wheat GFP, resulting in low final grain yields.

The extent of the vegetative phase (emergence to "boot", stage 1–10 Feeks scale) may impact the GFP and consequently, final yields (Evans and Wardlaw, 1976). Colville and Frey (1986) suggested that high temperatures may reduce duration of both vegetative and reproductive phases. High temperatures are often associated with drought or water stress conditions. This may impose growth limitations, such as early plant maturity or premature senescence, resulting in lower yields (Clarke et al., 1984; Sayed and Gadallah, 1983; Knott and Gebeyehou, 1987).

In Polk County, south central Florida, there are over 48,000 hectares of phosphatic clay settling areas resulting from the phosphate mining industry. The Florida legislature has made it mandatory that lands disturbed by mining should be reclaimed. Production of wheat and triticale as feed grains or forage crops on these phosphatic clays would benefit the state's feed deficient livestock industry while meeting the reclamation mandate. This practice would also provide economic stability for the county, when mining operations eventually terminate in the area. The high water holding capacity of these phosphatic clays may eliminate the need for irrigation while providing a good crop growth medium. However, in periods of heavy rains, this water holding property may cause delays in management operations (Hochmuth et al., 1987). Following rains, several days may elapse waiting infiltration or evaporation of perched water before field activity can take place. Management practices such as seeding may therefore be delayed. Delayed or late planting may cause crop growth and development to be pushed forward into periods of increased temperatures.

The literature is deficient in information on the production of small grain crops on phosphatic clays in a subtropical (or tropical) environment. The objective of this study was to determine the effect of a Florida (subtropical) environment on development and yield of adapted cultivars of wheat and triticale when seeded at different dates during the same growing season.

MATERIALS AND METHODS—Field studies were conducted at the Agrico site of the Mined Lands Research/Demonstration Project in Polk County, Florida. The site is located approximately 33 km southwest of the town of Bartow. The geographical location of Bartow is latitude 27°54 N and longitude 81°51 W with an elevation of 38.7 meters above sea level. Average annual rainfall is 1433 mm and average midnight temperature is 17°C (National Oceanic and Atmospheric Administration, 1986–88). The research area was part of a 200 hectare phosphatic clay settling pond (an area where the clay slurry is discarded following phosphate extraction).

Florida 301 (a winter/facultative) wheat and Florida 201 (a spring type) triticale, both developed at the North Florida Research and Education Center, Quincy, Florida, (Barnett and Luke, 1979, 1980) were grown on the site over the 1987 and 1988 growing seasons. In both seasons the land was disked, harrowed and power tilled twice to break up clods. In 1988 this process was followed by a 'mellowing period'. Mellowing describes the process whereby alternate wetting and drying cycles cause the large clay aggregates to crumble into smaller size particles. This allows for a more uniform seedbed.

The two cultivars were experimentally arranged in a randomized complete block design over two planting dates, early and late. The treatment combinations were replicated five times. Planting was on 21 November 1986 and 8 January 1987 for early and late planting, respectively in 1987 season and 10 December 1987 and 15 January 1988 also for early and late planting in 1988 season. The later planting in 1988 was due to inclement weather which prevented November planting similar to 1987. Each plot had seven rows, each 6.2m long with 17.5 cm between rows. Wheat was seeded at 90 kg ha^{-1} and triticale at 112 kg ha^{-1}.

Plots were fertilized with 112 kg ha^{-1} of K_2SO_4 at planting and 112 kg ha^{-1} of nitrogen supplied by NH_4NO_3 at early tillering (Feeks scale stage 2–4, Large, 1954). Plots were sprayed with Benlate (benomyl) and Sevin (carbaryl) both at 1.12 kg ha^{-1} in 1987 and with Dithane M45 (mancozeb) at 2.24 kg ha^{-1} and Lannate (methonyl) at 0.95 liter ha^{-1} in 1988, to control powdery mildew (*Erysiphe graminis* DC.) and aphids (*Schizaphis graminum* Rond). Temperature and rainfall data (measured in the town of Bartow) for the experimental period were extracted from publications of the National Oceanic and Atmospheric Administration (NOAA, 1986–88). Collected data included days to anthesis, days to harvest, days in GFP, aerial biomass yield, grain yield and yield components such as spike m^{-2}, kernel spike^{-1} and weight kernel^{-1}. To determine GFP, 25 spikes were (randomly) tagged 30 cm from either end of the five inner rows in each plot at anthesis. The crop was considered to be in anthesis when 50% (visual estimation) of the spikes had anthers extruded in the central spikelets (Gebeyehou et al., 1982b). Five of the tagged spikes were clipped from each plot weekly until final harvest. The spikes were oven dried at 60°C for 72 hours. After drying, spikes were weighed then threshed and the whole kernels collected, counted, and weighed. These data were used to determine dry weight accumulation.

Final harvests were carried out 30 April, to 1 May and 27 May for early and late planted treatments in 1987 and 28 to 29 April and 19 May for early and late planted treatments in 1988. The central 3 and 4.6 m of the five inner rows from each plot were harvested in 1987 and 1988, respectively. Harvested samples were collected and dried in a grain dryer and then threshed, cleaned and weighed for yield determination.

Kernels m^{-2} were determined by dividing the final grain yield m^{-2} by the individual kernel weight at final harvest. This assumes that the kernels in final yield represent those going through the period from anthesis to harvest, thereby eliminating any field or handling losses. Kernel dry matter accumulation m^{-2} was then calculated by multiplying kernel m^{-2} by the weekly kernel weight measured during the period from anthesis to final harvest.

Grain filling period was calculated by fitting polynomial regression equations up to fourth order, to the kernel dry matter accumulation m^{-2} vs. days after anthesis data. The equation with the highest significant order (from the appropriate F test) was then selected as the estimate for the parameter. The data were then fitted to the equation to determine the maximum derivative dw/dt, where dw = the change in dry matter accumulation and dt = the change in days after anthesis. The derivative was calculated as $w_2 - w_1/t_2 - t_1$ where w_1 and w_2 are kernel weight, and t_1 and t_2 are days after anthesis. This enabled instantaneous determination of dw/dt. This derivative (slope), which is the growth rate during the linear phase of kernel development, was then divided into the final grain yield m^{-2} to give the GFP (Gebeyehou et al., 1982b). Statistical analyses were performed using SAS PC program (SAS Software, 1988).

Growing conditions—Total rainfall in November of 1987 was 12.95 mm compared to 187.96 mm in November of 1988. The high rainfall in the early part of 1988 growing season made field operations difficult, consequently, planting was delayed for 18 days compared to 1987. Mean monthly night time temperature in 1987 was lowest (5°C) in January to February and highest (30°C) in March to May. In 1988, lowest mean monthly night time temperature (8°C) was observed in January to February but highest mean monthly night time (32°C) was in April to May.

An outbreak of powdery mildew occurred in the crops in the early part of both growing seasons, but the severity was more intense and lasted longer in 1987. Leaf spot (*Helminthosporium Sativum* Pam., King and Bakke) and leaf rust (*Puccinia recondita* tritici Desm.) also occurred in both seasons. In 1987, the leaf spot was severe and may have terminated kernel development, especially in the early planted treatments. Birds were also a pest problem in the field. Those observed included the red wing black bird (*Aegelaius phoeniceus* L.), the common grackle (*Quiscalus quiscula* L.), the boat-tailed grackle (*Quiscalus major* Vieillot), and the mourning dove (*Zenaida macroura* L.).

The early planted wheat reached anthesis about the 15th week both years, compared to late planted which reached anthesis in the 17th week in 1987 and 21st week in 1988. On the other hand, in 1987 the early planted triticale reached anthesis about the 12th week compared to the late planted which reached anthesis about the 19th week. In 1988, the early planted triticale reached anthesis in the 13th week while the late planted reached anthesis in the 16th week. Since the early planted treatments were seeded 6 to 7 weeks earlier than the late planted treatment, they had the advantage of growing for a longer period at the lower seasonal temperatures. In both growing seasons the average temperature during most of the vegetative period remained below 20°C for the early planted treatment but rose above 20°C during the same period for the late planted treatment. Higher temperatures will accelerate plant development and therefore reduce the period of the growth stages (Evans and Wardlaw, 1976; Colville Baltenberger and Frey, 1987). Fischer (1985), in studying the influence of cooling and heating on wheat development, found a reduction of up to 7 days in the vegetative period when the crop was subjected to increased heat.

RESULTS AND DISCUSSION—Grain yields, test weight and harvest index of the early planted treatments were lower in 1987 but higher in 1988 (Tables 1 and 2). In 1987 aerial biomass yields were higher for early planted treatments but harvest index was higher for the late planted treatments. In 1988, all response variables except harvest index were higher for early planted treatment compared to late planted treatment of both crops. Yield differences for early planted vs late planted treatments may be attributable to occurrence and duration of reproductive developments.

TABLE 1. Yield response of Florida 301 wheat to planting date at Agrico site Polk County over two growing seasons.

Variables	1987 Early	1987 Late	1988 Early	1988 Late
Grain yield (kg ha^{-1})	1010	1020	3130*	1620
Test weight (kg hl^{-1})	62	62	80*	75
Biomass yield (kg ha^{-1})	8090*	4610	8430*	5500
Harvest index (%)	12.5	22.1	37.1	29.4

* Means within season are significantly different (LSD 0.05).

As shown in Table 3 the number of days to anthesis were greater for early planted treatments compared to late planted treatments. The time to anthesis for early planted wheat was 9 days more in 1987 and 22 days more in 1988, while that for early planted triticale was 1 day more in 1987 and 10 days more in 1988. The reduction of the period to anthesis for late planted treatment may be due to the on-set of higher temperatures at a comparatively earlier stage of crop development. This is further supported by the duration of the grain filling period (GFP) which was observed to be 13 days more in 1987 and 6 days more in 1988 for early planted vs late planted wheat and 11 days more in 1987 and 8 days more in 1988, for early planted vs lated planted triticale (Table 4). This reduction in the GFP for late planted treatments was the result of the higher temperatures at anthesis and the remainder of the GFP. The average daily temperature at anthesis was 23°C for the late planted treatements and 20°C for the early planted treatments in both growing seasons. Reduction of the GFP due to increased temperatures is consistent with the results of previous research in greenhouse (Sofield et al., 1977; Warrington et al., 1977) and field studies (Weigand and Cuellar, 1981; Knott and Gebeyehou, 1987; Bruckner and Frohberg, 1987b). The yield reduction of early planted treatment compared to late planted treatment in 1987 may have been due to disease incidence which occurred early in crop development. Evans and Wardlaw (1976), Simmons (1987), and McCloud (1982) stated that pre and post-anthesis events, such as achieving optimum leaf area and maintaining a good crop canopy, are important for

TABLE 2. Yield response of Florida 201 triticale to planting date at Agrico site Polk County over two growing seasons.

Variables	1987 Early	1987 Late	1988 Early	1988 Late
Grain yield (kg ha^{-1})	1240	1430	3210*	1800
Test weight (kg hl^{-1})	62*	53	69*	66
Biomass yield (kg ha^{-1})	9130*	4290	8000*	5590
Harvest index (%)	13.5	33.4	40.1	32.2

* Means within season are significantly different (LSD 0.05).

TABLE 3. Observed occurrence of reproductive phase of Florida 301 wheat and Florida 201 triticale at Agrico site Polk County.

Crop	Time of planting	Days to anthesis		Days to harvest	
		1987	1988	1987	1988
Wheat	Early	108	104	160	143
	Late	99	82	139	123
Triticale	Early	87	89	160	143
	Late	86	75	139	123

grain yields. The flag leaf and spike are responsible for approximately 70% of the post-anthesis photosynthate going to the kernel, while up to 27% may come from pre-anthesis reserves. Consequently, if the crop canopy is damaged, assimilation and partitioning of photosynthate will be impaired.

Grain yield was significantly ($p < 0.01$) and positively correlated with biomass yield over the combined seasons ($r^2 = 0.42$) and during 1988 ($r^2 = 0.82$) (data not shown). This relationship suggests that developments during the vegetative period strongly influence the outcome of grain yields. Research emphasis in this area may help to clarify the inconsistency seen in the literature regarding the correlation or non-correlation of the vegetative period with final grain yield. Gebeyehou and co-workers (1982b) reported a simple correlation between grain yield and vegetative period but also stated that the correlation between kernel weight and vegetative period was highly significant. Since pre-anthesis development will affect grain yields (Evans and Wardlaw 1976), it follows then that the extent of the development phases should affect yield outcome. Dunphy and co-workers (1984) found a concomitant decrease in wheat grain yield with leaf area index (LAI) and that grain yield was positively correlated with LAI at anthesis. In small grains, root development ceases with the onset of the reproductive phase (Asana

TABLE 4. Calculated growth rates and grain filling period (GFP) of wheat and triticale at Agrico site Polk County, Florida, over two growing seasons.

Growing season	Crop	Planting date	Dry matter accumulation		
			m^{-2} day^{-1}	$Kernel^{-1}$ day^{-1}	GFP
			(g)	(g)	(days)
1987	Wheat	Early	3.03	1.08	33
		Late	5.11	1.04	20
	Triticale	Early	4.84	0.96	41
		Late	3.01	0.63	30
1988	Wheat	Early	10.15	1.58	31
		Late	6.48	1.35	25
	Triticale	Early	7.78	1.24	41
		Late	5.48	2.45	33

and Williams, 1965; Evans and Wardlaw, 1976). Therefore, the extent of their development at that stage will influence their nutrient harvesting ability, thus affecting the nutrient status of above ground plant development. It has been suggested (Comfort et al., 1988) that wheat crops with deeper penetrating roots were better able to reach subsoil N during grain filling. According to Bruckner and Frohberg (1987b) there was a positive relationship between grain yields and plant available water in the root zone of spring grown wheat. Tiller development and the length of the vegetative period will influence yield components thus affecting grain yield outcome (Gebeyehou et al., 1982b; Rocheford et al., 1988).

Test weight is a function of the packing, volume and density of the kernel. This may be affected by wrinkled, broken, damaged or unfilled kernels due to environmental conditions (Yamazaki and Briggle, 1969). The climatic conditions at the experimental site during the period of the research may have influenced the test weight of early planted vs late planted treatments, although there was no difference for wheat in 1987 (Table 2). Harvest index serves as an indication of the percentage of carbohydrate that goes into grain (Simmons, 1987). Early planted treatments had a greater harvest index compared to late planted (Tables 1 and 2). This may be attributed to growing conditions.

Dry matter accumulation rates of the early planted vs late planted treatments were lower for wheat in 1987 but higher in 1988, whereas early planted triticale had greater dry matter accumulation rates in both seasons (Table 4).

Both early planted and late planted treatments experienced similar temperatures for the greater part of the GFP. Although early planted treatments entered anthesis when average daily temperature was about 20°C compared to about 23°C for late planted treatments, both treatments completed the major portion of grain fill when the average temperatures were 25°C or above. The higher growth rates for early planted treatments (Table 4), especially in 1988, may have been due to better moisture availability. According to the data from NOAA, rainfall during the 1988 growing season was approximately 25% greater than rainfall during the 1987 growing season (data not shown). This conforms to the findings of Gebeyehou and coworkers (1982b) which stated that moisture from irrigation significantly increased grain filling rates in wheat.

Table 5 shows regression equations fitted for kernel dry matter accumulation vs days between anthesis and harvest for both crops over the seasons. In 1987, quadratic equations provided the best fit for the data. Kernel dry matter accumulation was highly significant ($p < 0.01$, $r^2 = 0.53$ to 0.78) for both crops. However, in 1988, linear equations were best fitted to the kernel dry matter accumulation data ($p < 0.01, 0.05$, $r^2 = 0.40$ to 0.91). This latter situation implies an abrupt growth termination under high temperatures. Growth rates of wheat were 1.08 and 1.04 mg kernel^{-1} day^{-1} in 1987 and 1.58 and 1.35 mg kernel^{-1} day^{-1} in 1988, for early planted and

TABLE 5. Regression equations for kernel dry matter accumulation (g m $^{-2}$) vs days between anthesis and harvest for Florida 301 wheat and Florida 201 triticale at Agrico site Polk County over two growing seasons.

Growing season	Parameters	Coefficients			
		Early planting		Late planting	
		Wheat	Triticale	Wheat	Triticale
1987	Intercept	−5.260	−40.5198	−32.4743	−0.6289
	Linear	5.6184	8.0705	10.5130	8.5143
	Quadratic	−0.0650	−0.0771	−0.1817	−0.1128
	R^2	0.78**	0.53**	0.69**	0.75**
1988	Intercept	−29.5134	−182.7581	−66.1505	−33.3394
	Linear	10.1543	7.785	6.4817	5.4773
	R^2	0.91**	0.84**	0.40*	0.68**

*, ** Model significant at the 0.05, 0.01 probability levels, respectively.

late planted treatments, respectively. Growth rates of triticale were 0.96 and 0.63 mg kernel^{-1} day^{-1} in 1987 and 1.24 and 2.45 mg kernel^{-1} day^{-1} in 1988, also respectively, for early planted and late planted treatments (Table 4). Simmons (1987), stated that kernel growth is often in the range of 1.4 to 2.0 mg kernel^{-1} day^{-1}. However, this may vary due to growing conditions. The growth rates realized in this study are consistent with the findings of Gebeyehou and co-workers (1982a) and Weigand and Cuellar (1981). Sofield and co-workers (1977), found that growth rates in wheat kernel increased from 0.90 to 1.39 mg kernel^{-1} day^{-1} when the temperature was increased from 15/10°C to 30/25°C. Increased growth rate is generally associated with a reduction in the period of grain fill and consequently a reduction in grain yield (Sayed and Gadallah, 1983; Fischer, 1985).

There was a high positive and significant ($p < 0.01$) correlation between days from anthesis and kernel dry matter accumulation (Tables 6 through

TABLE 6. Correlation coefficients for grain dry matter accumulation for Florida 301 wheat, 1987 growing season. Upper = early planted. Lower = late planted.

	Days between anthesis and harvest	Kernel weight m^{-2}	Weight kernel^{-1}	Weight spike^{-1}	Spike weight m^{-2}
Days between anthesis and harvest	-	0.80**	0.87**	0.67**	0.71**
		0.75**	0.84**	0.32	0.40*
Kernel weight m^{-2}			0.95**	0.88**	0.83**
			0.88**	0.56**	0.66**
Weight kernel^{-1}				0.87**	0.90**
				0.42	0.56**
Weight spike^{-1}					0.95**
					0.92**

*, ** Significant at the 0.05, 0.01 probability levels, respectively.

TABLE 7. Correlation coefficients for grain dry matter accumulation for Florida 201 triticale 1987 growing season. Upper = early planted. Lower = late planted.

	Days between anthesis and harvest	Kernel weight m^{-2}	Weight $kernel^{-1}$	Weight $spike^{-1}$	Spike weight m^{-2}
Days between anthesis and harvest		0.70** 0.77**	0.83** 0.84**	0.45** 0.38*	0.79** 0.48**
Kernel weight m^{-2}			0.89** 0.91**	0.20 0.16	0.77** 0.31
Weight $kernel^{-1}$				0.49** 0.46**	0.89** 0.58**
Weight $spike^{-1}$					0.56** 0.93**

*, ** Significant at the 0.10, 0.01 probability levels, respectively.

9). This supports previous reports attesting to the importance of an extended grain filling period. Both crops had positive correlation coefficients ranging from 0.40 to 0.93 for early planted and late planted treatments in 1987 (Tables 6 and 7) and 0.78 to 0.96 for early planted and late planted treatments in 1988 (Tables 8 and 9). Gebeyehou and co-workers (1982a) found highly significant ($p < 0.01$) and positive correlations between grain filling duration and yields, while Knott and Gebeyehou (1987) reported inconsistent and small correlations between the same two variables. Other studies, have found distinct negative correlation between the two factors (Bruckner and Frohberg, 1987b; Nass and Reiser, 1975; Wych et al., 1982; Sayed and Ghandorah, 1984). These contrasting reports suggest that the level of correlation or non-correlation may be due to conditions within specific environments.

TABLE 8. Correlation coefficient for grain dry matter accumulation of Florida 301 wheat, 1988 growing season. Upper = early planted. Lower = late planted.

	Days between anthesis and harvest	Kernel weight m^{-2}	Weight $kernel^{-1}$	Weight $spike^{-1}$	Spike weight m^{-2}
Days between anthesis and harvest		0.94** 0.63**	0.97** 0.95**	0.78** 0.76**	0.93** 0.86**
Kernel weight m^{-2}			0.98** 0.58**	0.88** 0.83**	0.95** 0.49*
Weight $kernel^{-1}$				0.85** 0.72**	0.97** 0.90**
Weight $spike^{-1}$					0.93** 0.90**

*, ** Significant at the 0.05, 0.01 probability levels, respectively.

TABLE 9. Correlation coefficients for grain dry matter accumulation of Florida 201 triticale, 1988 growing season. Upper = early planted. Lower = late planted.

	Days between anthesis and harvest	Kernel weight m^{-2}	Weight $kernel^{-1}$	Weight $spike^{-1}$	Spike weight m^{-2}
Days between anthesis and harvest		0.79*	0.95*	0.70*	0.91*
		0.91*	0.96*	0.83*	0.95*
Kernel weight m^{-2}			0.87*	0.83*	0.82*
			0.96*	0.88*	0.91*
Weight $kernel^{-1}$				0.76*	0.96*
				0.81*	0.93*
Weight $spike^{-1}$					0.81*
					0.92*

* Significant at the 0.01 probability level.

CONCLUSIONS—Late planting of wheat and triticale under south central Florida's subtropical climate cause the crops to be subjected to higher temperatures during the period of reproductive developments. This resulted in reduction of the duration of grain fill by up to 15 days for both crops. As a consequence, in 1988, grain yields for late planted wheat was reduced by 44 percent while that of late planted triticale was reduced by 48 percent. The positive and significant correlation between days after anthesis and dry matter accumulation parameters, indicates that grain yields would be increased with a more extended grain filling period. The correlation between (aerial) biomass and grain yields also suggests that developments during the vegetative period may strongly impact grain yields outcome. This may be clarified by further research on parameters such as leaf, root and spike developments over the growing season. The climatic conditions of south central Florida seem somewhat harsh for the production of temperate small grains such as wheat and triticale for grain purposes. However, the (biomass) dry matter yields suggests that the crops may be successfully grown on these phosphatic clay areas for forage purposes. Greater yields of both grain and forage may be realized when the crops are planted early in the growing season.

ACKNOWLEDGMENTS—This report resulted from a two year study conducted as part of the Polk County Mined Lands Agricultural/Research/Demonstration Project, located in Polk County, Florida. The project materialized mainly through the efforts of Mr. Gerald Stricker, Polk County Extension Director. Financial support for the study was provided by the Florida Institute of Phosphate Research, Polk County Board of County Commissioners and the University of Florida. Preparation of the manuscript was realized through the resources of Florida A&M University's Cooperative Extension Program, especially the typing skills and efforts of Ms. C.Y. Sermons.

LITERATURE CITED

ASANA, R. D. AND R. F. WILLIAMS. 1965. The effect of temperature stress on grain development in wheat. Aust. J. Agric. Res. 16:1–13.

Barnett, R. D. and H. H. Luke. 1979. Grain yield and agronomic characteristics of triticale in comparison with other small grains in Florida. Soil and Crop Sci. Soc. Fla. Proc. 38: 48–51.

——— and H. H. Luke. 1980. Florida 301 a new wheat for multiple cropping systems in north Florida. IFAS. Agric. Exp. Stn. Circ. S-273, 8 pp.

——— W. P. Smith, and D. L. Wright. 1982. Survey of Florida small grain acreage and uses 1981–82 season. Agron. Facts No. 131. Fla. Coop. Ext. Service. University of Florida, Gainesville, FL.

Bruckner, P. L. and R. C. Frohberg. 1987a. Stress tolerance and adaptation in spring wheat. Crop. Sci. 27:31–36.

——— and R. C. Frohberg. 1987b. Rate and duration of grain fill in spring wheat. Crop Sci. 27:451–455.

Clarke, J. M., T. F. Townley-Smith, T. N. McCaig, and D. G. Green. 1984. Growth analysis of spring wheat cultivars of varying drought resistance. Crop Sci. 24:537–541.

Colville, D. C. and K. J. Frey. 1986. Development rate and growth duration of oats in response to delayed sowing. Agron. J. 78:417–421.

Colville Baltenberger, D. C. and K. J. Frey. 1987. Genotypic variability in response of oat to delayed sowing. Agron. J. 79:813–816.

Comfort, S. D., G. L. Malzer, and R. H. Busch. 1988. Nitrogen fertilization of spring wheat genotypes: Influence on root growth and soil water depletion. Agron. J. 80:114–120.

Dunphy, D. J., E. C. Holt, and M. E. McDaniel. 1984. Leaf area and dry matter accumulation of wheat following forage removal. Agron. J. 76:871–874.

Evans, L. T. and I. F. Wardlaw. 1976. Aspects of the comparative physiology of grain yield in cereals. Pp. 301–359. *In*: Brady, N. C. (ed.) Advances in Agronomy. Academic Press, New York.

Fischer, R. A. 1985. Number of kernels in wheat crops and the influence of solar radiation and temperature. J. Agric. Sci., Camb. 105:447–461.

——— and R. Mauer. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29:897–912.

Gebeyehou, G., D. R. Knott, and R. J. Baker. 1982a. Rate and duration of grain filling in durum wheat cultivars. Crop Sci. 22:337–340.

——— D. R. Knott, and R. J. Baker. 1982b. Relationships among durations of vegetative and grain filling phases, yield components, and grain yield in durum wheat cultivars. Crop Sci. 22:287–294.

Hochmuth, G. J., E. A. Hanlon, and J. A. Stricker. 1987. Crop production on reclaimed phosphate-mined soils in Florida. Hort. Sci. 22:(2):189–191.

Knott, D. R. and G. Gebeyehou. 1987. Relationships between the lengths of the vegetative and grain filling periods and agronomic characters in three durum wheat crosses Crop Sci. 27:857–860.

Laing, D. R. and R. A. Fischer. 1977. Adaptation of semidwarf wheat cultivars to rainfed conditions. Euphytica 26:129–139.

Large, C. E. 1954. Growth Stages in Cereals—Illustrations of the Feeks scale. Plant Path. 3: 128–129.

Linville, D. E., R. F. Dale, and H. F. Hodges. 1978. Solar radiation weighting for corn growth models. Agron. J. 70:257–263.

McCloud, D. E. 1982. Crop yield dynamics. *In*: Third African Bureau Agricultural and Rural Development Workshop. IITA. Ibadan, Nigeria. 10–13 May.

Nass, H. G. and B. Reiser. 1975. Grain filling period and grain yield relationships in spring wheat. Can. J. Plant Sci. 55:673–678.

National Oceanic and Atmospheric Administration. 1986–88. Climatological Data. Florida. Vol. 90–92. Department of Commerce, Washington, D.C.

Rocheford, T. R., D. J. Sammons, and P. S. Baenziger. 1988. Planting dates in relation to yield and yield components of wheat in the middle Atlantic region. Agron. J. 80:30–34.

SAS Proprietary Software. 6.03. 1988. SAS Institute, Inc., Cary, NC.

SAYED, H. I. AND A. M. GADALLAH. 1983. Variation in dry matter and grain filling characters in wheat cultivars. Field Crops Res. 7:61–71.

——— AND M. O. GHANDORAH. 1984. Association of grain filling characteristics with grain weight and senescence in wheat under warm dry conditions. Field Crops Res. 9:323–332.

SIMMONS, S. R. 1987. Growth, development and physiology. Pp. 77–113. *In*: HEYNE, E. G. (ed.) Wheat and Wheat Improvement, 2nd edition. ASA-CSSA-SSSA, Madison, WI.

SOFIELD, I., L. T. EVANS, M. G. COOK, AND I. F. WARDLAW. 1977. Factors influencing the rate and duration of grain filling in wheat. Aust. J. Plant Physiol. 4:785–797.

WARDLAW, I. F., I. SOFIELD, AND P. M. CARTWRIGHT. 1980. Factors limiting the rate of dry matter accumulation in the grain of wheat grown at high temperatures. Aust. J. Plant Physiol. 7:387–400.

WARRINGTON, I. J., R. L. DUNSTONE, AND L. M. GREEN. 1977. Temperature effects at three development stages on the yield of the wheat ear. Aust. J. Agric. Res. 28:11–27.

WEIGAND, C. L. AND J. A. CUELLAR. 1981. Duration of grain filling and kernel weight of wheat as affected by temperature. Crop Sci. 21:95–101.

WYCH, R. D., R. L. MCGRAW, AND D. D. STUTHMAN. 1982. Genotype X year interaction for length and rate of grain filling in oats. Crop Sci. 22:1025–1028.

YAMAZAKI, W. T. AND L. W. BRIGGLE. 1969. Components of test weight in softwheat. Crop Sci. 9:457–459.

Florida Scient. 60(2): 124–135. 1997
Accepted: November 22, 1996.

INSTRUCTION TO AUTHORS

Individuals who wish to publish in the *Florida Scientist* must be active members in the Florida Academy of Sciences.

Submit a typewritten original and two copies of the text, illustrations, and tables to the editors. All typewritten material–including the abstract, literature citations, footnotes, tables, and figure legends–shall be double-spaced. Use one side of 8½ × 11 inch (21½ cm × 28 cm) good quality bond paper for the original; the copy may be xeroxed. Margins should be at least 3 cm all around. Number the pages through the Literature Cited section. Avoid footnotes and do not use mimeo, slick, erasable, or ruled paper. Use metric units for all measurements. *Papers in excess of 10 pages by an author in a single volume will result in page charges ($57 per page) for the excess pages.*

Address follows the author's name.

Abstract–all manuscripts shall have a short, concise, single-paragraphed abstract. The abstract follows immediately the author's address.

Acknowledgments are given in the body of the text preceding immediately the Literature Cited section.

Literature Cited section follows the text. Double-space every line and follow the format in the current issue.

Manuscripts of 5 or less, double-spaced typewritten pages should conform to the short article protocol. See recent issue for proper format of both long and short articles.

Tables shall be typed on separate sheets of paper, double-spaced throughout. Each table shall contain a short heading. Do not use vertical rulings. Maximum character width, including spaces, of tables is 98.0. This includes a minimum space of 5 characters between columns.

Illustrations–All drawings shall be done in good quality India ink, on good board or drafting paper. Letter by using a lettering guide or equivalent. Typewritten letters on illustrations are unacceptable. Drawings and photographs should be large enough to allow ⅓ to ½ reduction in size. Photographs shall be glossy prints of good contrast. Whenever possible, mount photographs in lots size.

The author's name and figure number should be penciled lightly on the back of each figure. Figure legends must be listed on a separate page and not on the drawing or photograph. The legend must be double spaced. Illustrations are charged to authors at $16.00 for halftones and $11.00 for line art.

We ask authors to prepare accepted manuscripts in personal computer formats. **Please do not submit a manuscript on disk.** Once reviewers have recommended a manuscript be accepted, you will be given directions for submitting the **final manuscript on disk.**

Proof must be returned promptly. Notification of address change and proofreading are the author's responsibility. Alterations after the type has been set will be charged to the author.

Reprints may be ordered through the Business Manager from the printer on forms provided at the time that proofs are sent to authors for checking.

FLORIDA ACADEMY OF SCIENCES

Institutional Members for 1997

Brevard Community College, Palm Bay
The British Library, Boston Spa, Weatherby, UK
The British Library, RAS Washington DC
    Professional Campus
Cleveland Public Library, Cleveland, OH
Edison Community College
Florida International University
Harbor Branch Oceanographic Institution, Inc.
Long Island University
St. Petersburg (FL) Junior College
St. Thomas University
St. Thomas University Library
Saint Petersburg Public Library
Science Library, University of Chicago
University of Miami
University of North Carolina at Wilmington

Membership applications, subscriptions, renewals, and changes of address, should be addressed to the Executive Secretary, Florida Academy of Sciences, Orlando Science Center, 777 Princeton St., Orlando, FL 32803

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 University Blvd., Melbourne, FL 32901-6975 [(407) 768-8000, ext. 8196; e-mail rturner@fit.edu]

PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Special bargain: $500 for nearly complete sets. Prices quoted include domestic postage. Some issues may not be available. All are $20 per volume or $5 per issue, except for symposium issues.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES (1936–1944)
  Volumes 1–7
QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCE (1945–1972)
  Volumes 8–35
FLORIDA SCIENTIST (1973)
Florida's Estuaries—Management or Mismanagement?—Academy Symposium
  FLORIDA SCIENTIST 37(4)–$5.00
Land Spreading of Secondary Effluent—Academy Symposium
  FLORIDA SCIENTIST 38(4)—$5.00
Solar Energy—Academy Symposium
  FLORIDA SCIENTIST 39(3)—$5.00 (includes do-it-yourself instructions)
Anthropology—Academy Symposium
  FLORIDA SCIENTIST 43(3)—$7.50
Shark Biology—Academy Symposium
  FLORIDA SCIENTIST 45(1)—$8.00
Future of the Indian River System—Academy Symposium
  FLORIDA SCIENTIST 46(3/4)—$15.00
Second Indian River Research Symposium—Academy Symposium
  FLORIDA SCIENTIST 53(3)—$15.00

Please send payment with order. If required, an invoice will be sent on purchases over $20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.

Q
11
F6F63
NH

ISSN: 0098-4590

Florida Scientist

Volume 60 Summer, 1997 Number 3

CONTENTS

Selected Life History Attributes of the Exotic Jaguar Guapote (*Cichlasoma managuense*) in Florida .... Kelly Gestring and Paul Shafland 137

Pollination Ecology of the Rare Scrub Mint *Dicerandra frutescens* (Lamiaceae) .... Mark Deyrup and Eric S. Menges 143

The Effects of Azadirachtin on Larval Stages of the Oak Toad, *Bufo quercicus* (Holbrook) .... Fred Punzo 158

Literature Search for Air Quality Studies Conducted in Jacksonville, Florida, 1945–1995 .... R. Del Delumyea, Tonya McKay, and Jennifer Horowitz 166

Trends in Air Quality Research in Northeast Florida, 1945–1995 and Comparison of Air Quality in Jacksonville, FL with Nine Other Cities in the United States, 1972–1992 .... R. Del Delumyea, Tonya McKay, and Jennifer Horowitz 175

Utility of a Camera System for Investigating Gopher Tortoise Burrows .... Donald M. Kent, Michael A. Langston, David W. Hanf, and Peter M. Wallace 193

Observations of Vertebrates Associated with Gopher Tortoise Burrows in Orange County, Florida .... Donald M. Kent, Michael A. Langston, and David W. Hanf 197

Identification of Allelopathic Chemicals in a Pond of Cattails .... Joaquìn Albalat Domènech, Eileen Pérez, Maria T. Gallardo, and Dean F. Martin 202

Florida Academy of Sciences Medalists 204

SMITHSONIAN
AUG 2 1 1997
LIBRARIES

FLORIDA SCIENTIST

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Copyright© by the Florida Academy of Sciences, Inc. 1997

Editor: Dr. Dean F. Martin Co-Editor: Mrs. Barbara B. Martin
Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, Florida 33620-5250
Phone: (813) 631-4121; e-mail: Martin@chuma.cas.usf.edu

Business Manager: Dr. Richard L. Turner
Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975
Phone: (407) 768-8000, ext. 8196; e-mail: rturner@fit.edu

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at $40.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

Officers for 1997–1998
FLORIDA ACADEMY OF SCIENCES
Founded 1936

President: Mr. Al Hall
City of Tallahassee
4335 Sherborne Road
Tallahassee, FL 32303

President-Elect: TBA

Secretary: Dr. Richard March
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416

Treasurer: Mrs. Georgina Wharton

Executive Secretary: Ms. Geralyn Heartz
Orlando Science Center
777 East Princeton St.
Orlando, FL 32803
407:896-7151, ext 2079; e-mail:
heartzfas@hotmail.com

Program Chairs: Dr. George M. Dooris
and Dr. Patricia M. Dooris
Department of Science and Mathematics
St. Leo College
St. Leo, FL 33574

Published by The Florida Academy of Sciences, Inc.
Printing by Allen Press, Lawrence, Kansas

Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

DEAN F. MARTIN, *Editor* BARBARA B. MARTIN, *Co-Editor*

Volume 60 Summer, 1997 Number 3

Biological Sciences

SELECTED LIFE HISTORY ATTRIBUTES OF THE EXOTIC JAGUAR GUAPOTE (*CICHLASOMA MANAGUENSE*) IN FLORIDA

KELLY GESTRING AND PAUL SHAFLAND

Non-Native Fish Research Laboratory, Florida Game and Fresh Water Fish Commission,
801 NW 40th Street, Boca Raton, FL 33431

ABSTRACT: *The jaguar guapote (*Cichlasoma managuense*) was added to Florida's list of established exotic fishes in 1995. Jaguar guapotes were collected for 12 consecutive months from the Little River Canal (C-7), Florida. Fish and insects were the primary food. Males grow larger than females (only three of 59 guapotes ≥301 mm TL were females). During 1994–95, jaguar guapotes spawned primarily between March and November with a peak in July. Fecundity estimates for ripe female jaguar guapotes averaged 4,053 (n = 17; 29 eggs/g whole fish weight).*

THE JAGUAR guapote (*Cichlasoma managuense,* Fig. 1) is a large predatory cichlid native to the rivers, lakes, and estuaries of Central America. It is a recent addition to the established exotic fish fauna of Florida with the first documented evidence of its unauthorized introduction occurring in July 1992 (Shafland, 1996). Jaguar guapotes are sensitive to cold temperatures (lower lethal temperature = 12° C, Shafland, 1996) which will restrict their distribution to an area largely south of Tampa (Shafland and Pestrak, 1982). The purpose of this study is to document the stomach contents, sex ratios, spawning seasonality, and fecundity of jaguar guapotes in Florida.

STUDY SITE—The Little River Canal is part of the extensive canal system of southeast Florida (Fig. 2). It is located in northeastern Dade County and is designated as the C-7 canal by the South Florida Water Management District. It is comprised of several small lateral canals connected to the central main canal. The main Little River Canal is approximately 14 km long, 20 to 22 meters wide, and 3 to 4 meters in depth.

Little River Canal has vertical walls cut into the coral rock substrate. The primary function

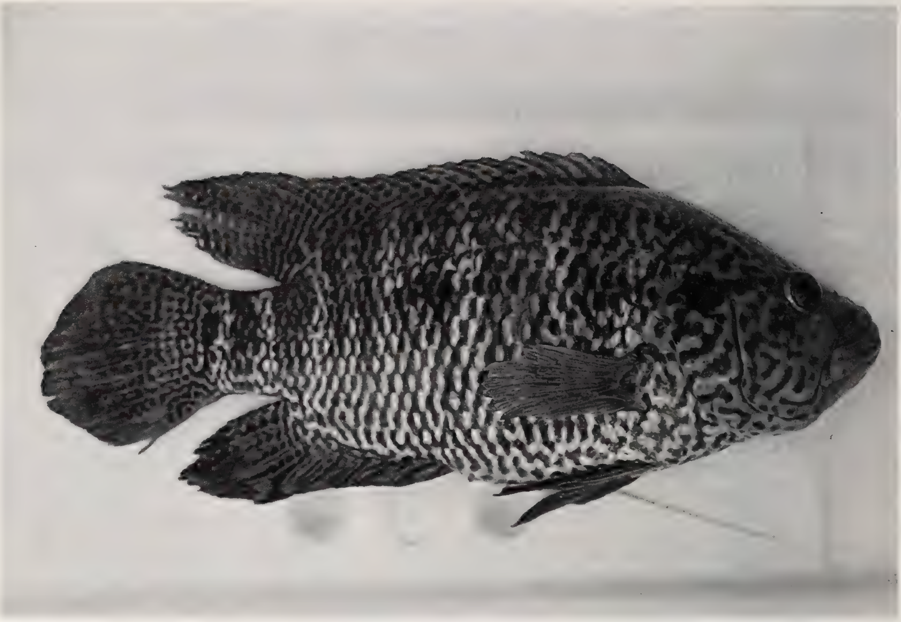


FIG. 1. An adult jaguar guapote (*Cichlasoma managuense*) from the Little River Canal, Florida.

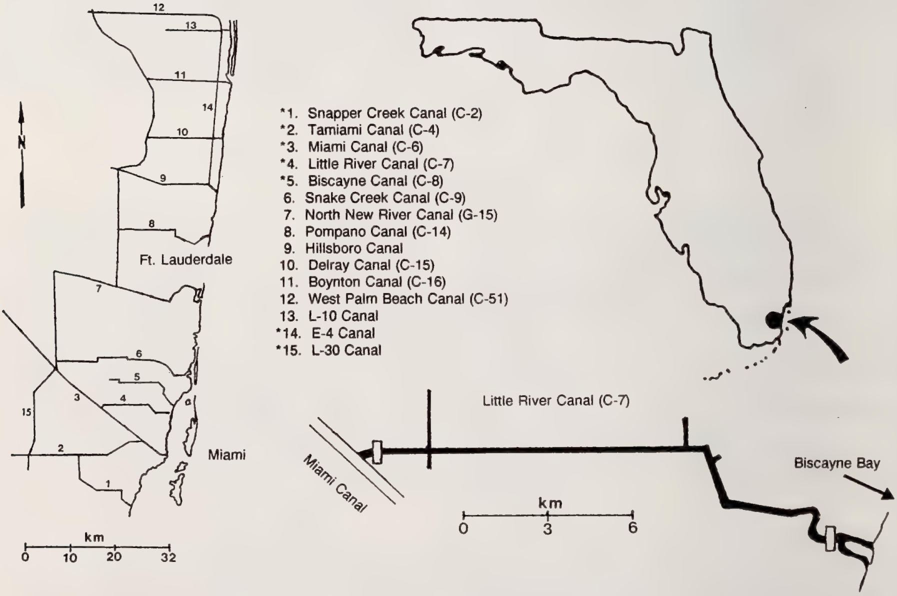


FIG. 2. Main canals in the known range of jaguar guapotes (*Cichlasoma managuense*) in Florida, and a diagrammatic sketch of the Little River Canal system. Asterisks identify canals from which jaguar guapotes have been collected.

TABLE 1. Index of relative importance values for the three major prey categories found in the stomach contents of jaguar guapotes containing identifiable prey items (numbers in parentheses are the sample sizes or total volume).

Prey Category	Frequency of Occurrence	Percentage of Prey Items	Percentage of Prey Volume	Index of Relative Importance
All fish (n = 100)				
Fish	50.0 (50)	8.5 (110)	91.6 (188.4)	5,005
Insects	49.0 (49)	91.3 (1,183)	4.4 (9.0)	4,689
Other[1]	3.0 (3)	0.2 (3)	4.0 (8.3)	13
Fish <200 mm TL (n = 72)				
Fish	40.3 (29)	5.7 (71)	68.4 (14.5)	2,986
Insects	56.9 (41)	94.2 (1,163)	31.1 (6.6)	7,480
Other[1]	1.4 (1)	0.1 (1)	0.5 (0.1)	1
Fish >200 mm TL (n = 28)				
Fish	75.0 (21)	63.9 (39)	94.3 (173.9)	11,865
Insects	21.4 (6)	24.7 (20)	1.3 (2.4)	556
Other[1]	7.1 (2)	3.3 (2)	4.4 (8.2)	55

[1] Other = Annelid, Turtle, and Lizard.

of this canal is surface water drainage and flood control. There is a one to two meter wide shoreline fringe of submergent vegetation consisting primarily of hydrilla (*Hydrilla verticillata*). Nearly all of the shoreline is residentially developed.

METHODS—A maximum of 20 jaguar guapotes from each 50 mm TL (total length) size class were collected by electrofishing for 12 consecutive months from the Little River Canal (C-7) beginning in June 1994. Lengths and weights were recorded, and stomach contents removed, identified and counted. Volume of prey items was determined to the nearest 0.1 ml by volumetric displacement.

The percent frequency of occurrence (%F), percent total number (%N), and percent total volume (%V) were calculated for all organisms found in the stomachs. These data were used to generate an index of relative importance (IRI) value for each prey item or prey group using the equation derived by Pinkas and co-workers (1971): $IRI = \%F(\%N + \%V)$.

Gonads were removed and the sex determined by direct or microscopic examination. Gonads were blotted dry, weighed, and the gonadal-somatic indices (GSI = gonad weight divided by the whole body weight) were calculated (Snyder, 1983). Stages of gonadal development were defined as immature (eggs not easily discernible; testes appeared as thin strings), mature (individual eggs obvious but irregular in size; testes noticeably enlarged, whitish in color), and ripe (eggs uniform in shape and size; testes large, limp, somewhat flattened in shape). Fecundity for 17 ripe females was estimated by extrapolating the weight of approximately 100 eggs to the whole ovary weight.

RESULTS—A total of 645 jaguar guapote stomachs were examined; of these, 66% were empty, 122 contained unidentifiable prey items, and 100 contained identifiable prey items. Overall, fish had the highest IRI value, followed by insects (Table 1). Of the 25 fish found in stomachs which could be identified to species, 19 were exotics. The exotics were comprised of ten

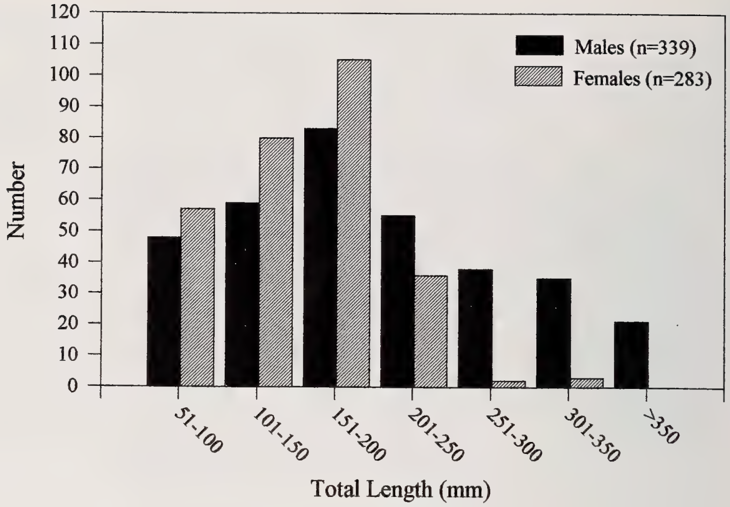


FIG. 3. Number of male and female jaguar guapotes in 50-mm size classes collected from the Little River Canal, June 1994 through May 1995.

spotted tilapia (*Tilapia mariae*), four oscars (*Astronotus ocellatus*), three jaguar guapote (*Cichlasoma managuense*), and two black acara (*Cichlasoma bimaculatum*). Mosquitofish (*Gambusia affinis*) were the only native fish species consumed. Other identified prey items were insects, a small turtle, a lizard, and a small section of an annelid worm.

Insects had the highest IRI for small jaguar guapotes (<200 mm TL) followed by fish (Table 1). This order was reversed in jaguar guapotes ≥200 mm TL.

Of the 670 jaguar guapotes examined, 622 (93%) could be sexed. The sex of jaguar guapotes could be distinguished by dissection for fish as small as 70 mm TL. Males grow larger than females with the largest male measuring 402 mm TL while the largest female was 345 mm TL. Females made up 45% of the sexed fish. With the exception of the smallest size class examined, the percentage of females decreased with increasing length, and changed from 57% (n=327) for jaguar guapotes 101 to 200 mm TL to 29% (n=131) for fish 201 to 300 mm TL; only three guapotes ≥301 mm TL (n=59) were females (Figure 3).

The smallest male and female jaguar guapote considered sexually mature were 135 and 116 mm TL, respectively. All females ≥222 mm TL, and males ≥264 mm TL were mature. Monthly GSIs indicated most jaguar guapotes spawned between March and November with a peak in July (Table 2), although at least one ripe fish was collected every month except December and January.

The mean fecundity estimate for 17 ripe female jaguar guapotes ranging in size from 151 to 304 mm TL was 4,053 eggs (sd = 2,774, range = 1,410

TABLE 2. Number of mature and ripe jaguar guapotes collected from the Little River Canal, June 1994 through May 1995.

	Male				Female				Smallest Ripe Fish (TL mm)	
Month	N	Mature	Ripe	GSI	N	Mature	Ripe	GSI	Male	Female
June	30	20	10	0.12	21	18	3	1.20	235	154
July	21	13	8	0.12	18	10	8	2.60	261	162
Aug	19	13	6	0.12	14	13	1	0.75	266	191
Sept	20	9	11	0.13	20	13	6	1.78	203[1]	162
Oct	11	6	5	0.12	11	5	6	3.06	350	151[1]
Nov	9	8	1	0.10	10	7	3	2.49	363	153
Dec	8	8	0	0.08	7	7	0	0.79	—	—
Jan	9	9	0	0.05	5	5	0	0.27	—	—
Feb	10	8	2	0.07	5	5	0	0.44	375	—
Mar	11	9	2	0.05	3	2	1	1.93	346	304
Apr	20	11	9	0.13	7	4	3	2.49	237	152
May	26	18	8	0.14	6	3	3	2.19	245	161

[1] These are the smallest (mm TL) male and female jaguar guapotes collected with ripe gonads.

to 13,447). The mean number of eggs per gram of whole fish was 29 (sd = 5, range = 20 to 42). These values tended to be higher in larger than in smaller females.

Grand mean length and width measures of five eggs from each of 17 ripe jaguar guapote females were 1.98 mm (sd = 0.12, range = 1.82 to 2.12) and 1.39 mm (sd = 0.07, range = 1.29 to 1.44), respectively. Ripe eggs were smooth, light yellow in color and generally resembled a chicken egg in shape with a narrowing of one end.

The mean condition factor (KSL = weight (g) × 10^5 / standard length^3 (mm), Anderson and Gutreuter, 1983) for all jaguar guapotes was 4.13 (n = 670, sd = 0.54, range = 1.81 to 9.49). Monthly means ranged from 4.06 to 4.29. The overall mean KSL for female jaguar guapotes was 4.23 (n = 283; sd = 0.34; range = 3.29 to 6.03), and 4.16 for males (n = 339; sd = 0.34; range = 2.84 to 5.13).

DISCUSSION—Larger jaguar guapotes were primarily piscivorous, although insects were more common in fish <200 mm TL. These findings generally support those of Astorqui (1971), Barlow (1976), Baylis (1974), and Dunseth and Bayne (1978), who also found jaguar guapotes to be highly piscivorous.

Jaguar guapotes have pharyngeal teeth which masticate large prey items (especially fish). This made the species identification of most food items in the stomachs impossible. The near absence of native fishes in jaguar guapote stomachs is likely due to the presence of relatively few native fishes in the Little River Canal fish community (personal observation).

In their native range, jaguar guapotes occur in a variety of habitat types within their riverine and lake distributions. These include muddy, sandy, and rocky bottoms, boulder falls, rocky cliffs, and areas of overhanging and submergent macrophytic vegetation (Bleick, 1970). Jaguar guapotes in the Little River Canal were associated primarily with the shoreline fringe of hydrilla, and in shallow areas with dense, submergent macrophytes. The known range of jaguar guapotes has expanded from the Tamiami (C-4), Miami (C-6), and Biscayne (C-8) Canals in 1993 to include the area bounded by Snapper Creek Canal (C-2) to the south, the L-10 Canal in Palm Beach County to the north, the E-4 Canal to the east, and the L-30 Canal to the west in 1995 (Fig. 1). These data suggest the jaguar guapote is continuing to expand its range.

ACKNOWLEDGMENTS—I would like to thank P. L. Shafland for initiating this project, P. L. Shafland, S. Hardin, and an anonymous reviewer for helpful critiques of this manuscript, and M. S. Stanford and N. J. Musselman for their field work assistance.

LITERATURE CITED

ANDERSON, R. O. AND S. J. GUTREUTER. 1983. Length, weight, and associated structural indices. Pp. 283–300. *In*: NIELSON, L. A. AND D. L. JOHNSON (ed.), Fisheries Techniques. American Fisheries Society, Bethesda, MD.

ASTORQUI, I. 1971. Pesces de la cuenca de los grandes lagos de Nicaragua. Rev. Biol. Trop. 19(1,2):7–57. *Cited in*: THORSON,T.B. (ed.) 1976, Investigations of the Ichthyofauna of Nicaraguan Lakes. School of Life Sciences, University of Nebraska, Lincoln, NE.

BARLOW, G. W. 1976. The Midas cichlid in Nicaragua. Pp. 333–358. *In*: THORSON, T.B. (ed.), Investigations of the Ichthyofauna of Nicaraguan Lakes. School of Life Sciences, University of Nebraska, Lincoln, NE.

BAYLIS, J. R. 1974. The behavior and ecology of *Herotiliapia multispinosa* (Teleostei, Cichlidae). Z. Tierpsychol. 34:115–146. *In*: THORSON, T.B. (ed.)Investigations of the Ichthyofauna of Nicaraguan Lakes. School of Life Sciences, University of Nebraska, Lincoln, NE.

BLEICK, C. R. 1970. The behavior of a central American cichlid fish, *Cichlasoma managuense,* and the function of its color patterns: A laboratory field study. Berkeley: University of California. Thesis. 1–118.

DUNSETH, D. R. AND D. R. BAYNE. 1978. Recruitment control and production of *Tilapia aurea* (Steindachner) with the predator, *Cichlasoma managuense* (Gunther). Aquaculture 14: 383–390.

PINKAS, L., M. S. OLIPHANT, AND L. L. IVERSON. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. California Fish and Game, Fish Bulletin 152.

SHAFLAND, P. L. 1996. Status of exotic fishes in Florida. Rev. Fish. Sci. 4(2):101–122.

——— AND J. M. PESTRAK. 1982. Lower lethal temperatures for fourteen non-native fishes in Florida. Environ. Biol. Fish. 7(2):149–156.

SNYDER, D. E. 1983. Fish eggs and larvae. Pp. 165–198. *In*: NIELSON, L. A. AND D. L. JOHNSON, (ed.), Fisheries Techniques. American Fisheries Society, Bethesda, MD

Florida Scient. 60(3): 137–142. 1997
Accepted: December 10, 1996.

POLLINATION ECOLOGY OF THE RARE SCRUB MINT *DICERANDRA FRUTESCENS* (LAMIACEAE)

Mark Deyrup and Eric S. Menges

Archbold Biological Station, P.O. Box 2057, Lake Placid, FL 33862

Abstract: *We examined pollination in natural populations of the rare Florida scrub endemic* Dicerandra frutescens *(Lamiaceae) to determine if pollinator specialization or poor pollinator service were factors in this species' restricted range and decline. Pollinators were observed in six populations in timed watches at various times of day, on plants of different sizes, and in different conditions. The bee fly* Exprosopa fasciata *(Diptera: Bombyliidae) made 95% of all visits, and an average flower received about 46 bee fly visits. Plants in more open sites, plants with more flowers, and sun-lit plants received significantly more visits. Bee-flies contact anthers in the morning, while stigmas bend up to receive pollen in the afternoon. The structure of* D. frutescens *flowers is specialized for large insects with long tongues. A system of concealed pollen and triggered pollen release may protect pollen from smaller insects and desiccation. Pollen deposition on the undersides of visiting insects suggests fly, rather than bee pollination. Related Dicerandra species with different pollinators have structurally-different flowers. Based on the large numbers of visits and the observed movements of the bee fly, pollinator limitation appears unlikely. Furthermore, the bee fly is a common species that feeds on many plant species. Although* Dicerandra frutescens *is highly dependent on a single pollinator, it is unlikely that this has contributed to its rarity nor made it vulnerable to extinction. Instead, microhabitat specificity, habitat destruction, and fire-suppression are the major threats.*

The Lake Placid scrub mint, *Dicerandra frutescens* Shinners (Lamiaceae) is a federally listed endangered plant that grows on a few sites near the town of Lake Placid, Highlands County, Florida. *Dicerandra frutescens* is one of several relict plant species confined to Florida scrub habitat on the Lake Wales Ridge, a narrow dune system in the center of the Florida peninsula (Christman and Judd, 1990). The Lake Placid scrub mint has been the subject of several research projects, not only because it is a rare and beautiful plant, but also because it has intriguing biological features, including its unusual chemical defenses (Eisner et al., 1990; Smedley et al., 1990; McCormick et al., 1993), its stringent requirements for specific soil types and microhabitats (Menges, 1992), its problematic taxonomic relationships to other members of its genus (Huck, 1987; Huck et al., 1989), and its remarkably restricted geographic range (Huck, 1987; Huck et al., 1989; Christman and Judd, 1990).

The breeding system of the Lake Placid scrub mint was studied by Huck (1987). She reported that *Dicerandra* species, including *D. frutescens,* are obligate outcrossers. However, some seeds produced by selfing were able to germinate and produce seedlings, suggesting that *D. frutescens* is self-com-

TABLE 1. Summary for *Dicerandra frutescens* populations at Archbold Biological Station sampled in this study.

Pop. No.	Name	Soil	Vegetation	Plant Density/ m^2 (1988)	Fire History (1967–1990)
0	Pole 49	Astatula	Abandoned firelane	22.5	None
11	East Firelane	Astatula	Abandoned firelane	1.8	1990
10	Cowpen	Astatula	Oak-hickory scrub*	0.5	1985
12	18E Hickory	Orsino	Oak-hickory scrub*	2.9	1990
2	Scrub Grid	Paola	Sand pine scrub	3.3	None
4	Scrub East	Paola	Sand pine scrub	1.9	None

* Termed hickory phase sandhill by Abrahamson et al. 1984.

patible by the usual definitions. Huck (1987) also described the peculiar way in which *Dicerandra* species deposit pollen on visiting insects, and made preliminary field observations on insects visiting *Dicerandra* species. Our study was specifically motivated by Huck's conclusion that the pollination mechanism in *Dicerandra* species is highly specialized, leaving populations highly vulnerable to changes in local guilds of pollinator insects. Our study of pollination of *D. frutescens,* therefore, had a practical conservation goal: we wished to discover whether there is anything about the pollination ecology of this plant that would explain its rarity or threaten populations in the remaining small patches of habitat where this species still persists.

SITES AND METHODS—*Dicerandra frutescens* was studied at the Archbold Biological Station (Highlands County, Florida), where the plants grow on yellow sand ridges in a habitat characterized by *Carya floridana* Sargent, *Quercus myrtifolia* Willdenow, *Q. chapmanii* Sargent, *Q. geminata* Small, *Lyonia ferruginea* (Walter) Nuttall, and a variable canopy of *Pinus clausa* (Chapman ex Engelmann) Vasey ex Sargent or *P. elliottii* var. *densa* Little and Dorman. These habitats are described in detail by Abrahamson et al. (1984) under the categories of sand pine scrub and hickory phase sandhill (the latter termed oak-hickory scrub in this paper). Six populations were studied, 2 from mature sand pine scrub, 2 from oak-hickory scrub, and 2 from abandoned firelanes adjacent to oak-hickory scrub (Table 1). These three site types form a series from mostly shaded, to partly shaded, to mostly unshaded (Menges, 1992).

Flower visitation observations lasted 5 minutes per plant. Plants were selected to span a range of sizes. We recorded for each observation: population designator, date, general weather conditions, time of day, number of flowers on the plant, number of cream or white flowers, whether the plant was shaded or sunlit during the observation, number and species of insects visiting the plant, number of visits by each insect species. Observations sampled the period from 8:30 a.m. to 4:30 p.m. A total of 467 observations were made, 11–27 September, 1989. Analyses predicted numbers of individuals, numbers of visits, and visits per flower to the other variables, using one-way and multiple analysis of variance.

Extensive non-timed flower observations were made over several years, with photographic documentation of pollinator and flower movements. In addition, expeditions were made to Sebring (Highlands County), Fort Pierce (St. Lucie County), and Ocala (Marion County) to observe insect visitors on other species of *Dicerandra*.

Plant nomenclature, including author names, follows Wunderlin (1982).

TABLE 2. Flower visitors to *Dicerandra frutescens*, based on 467 5-minute watches.

Visitor	Visits per Watch	% of all Visits	Type of Interaction
Exprosopa fasciata (Diptera: Bombyliidae)	1.620	94.7	Primary pollinator
Dialictus spp. (Hymenoptera: Halictidae)	0.010	0.6	Pollen robber
Augochlorella sp. (Hymenoptera: Halictidae)	0.047	2.7	Nectar and/or pollen robber
Megachilidae (Hymenoptera)	0.015	0.9	Nectar robber, occasional pollinator
Caupolicana electa (Hymenoptera: Colletidae)	0.002	0.1	Nectar robber
Apis mellifera (Hymenoptera: Apidae[1])	—	—	Possible pollinator
Bombus spp. (Hymenoptera: Apidae)	0.004	0.2	Nectar robber or pollinator
Synanthedon (Lepidoptera: Sesiidae)	0.002	0.1	Possible pollinator
Ants (Hymenoptera: Formicidae)	0.004	0.2	Casual on flowers
unknown	0.006	0.5	—

[1] Has been observed on flowers outside of timed flower watches.

RESULTS AND DISCUSSION—*Visitors and visitation rates*—The bee fly *Exprosopa fasciata* Macquart (Diptera: Bombyliidae) was clearly the most important pollinator for *Dicerandra frutescens*. Bee flies were noted at all sites and during all times of day (8:30 a.m.–4:30 p.m.), being most abundant in open sites, and when the sun was shining. During an average 5-min watch of several plants, beeflies made 1.6 visits, or about 95% of all visits (Table 2). The next most important visitors (various halictid bees) are nectar or pollen robbers and do not appear to be pollinators. Other possible pollinators are extremely uncommon visitors on *Dicerandra frutescens* at Archbold, comprising less than 1% of observed visits. Because *E. fasciata* is the only important pollinator for *D. frutescens*, analyses of ecological factors affecting visitation are made for this species only.

On the average, each flower received visits from 0.32 *E. fasciata* individuals during a 5-min watch. An average *E. fasciata* individual visited 5.34 different flowers in 5 min. Assuming 12 hr of visitation, each flower would be visited by about 46 flies.

Visitation rates varied widely among *Dicerandra frutescens* habitats. The two firelane populations and the more open, more recently-burned of the two oak scrub sites received over 0.4 visits per flower per watch. Other

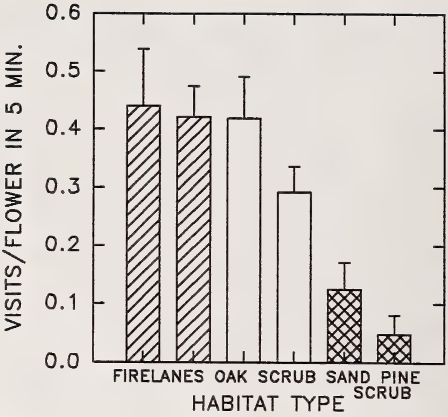


FIG. 1. Visits by *Exprosopa fasciata* to *Dicerandra frutescens* in two examples in each of three scrub habitat types.

populations received less than 0.3 visits per flower (Fig. 1). Population differences in visits per flower were significant (one-way ANOVA, F = 4.6, df = 5, p = 0.0004).

Population differences in visitation rates are consistent with flower densities per plant. Of flowering plants observed in the study, firelane population plants averaged over 35 flowers per plant, oak scrub populations 5–15 flowers per plant, and sand pine scrub plants less than 5 flowers per plant (Fig. 2). Population differences for flowers per plant were highly significant (one-way ANOVA, F=32.5, df=5, p<0.0000). Because flowering plant densities are also lowest in sand pine scrub, flower densities per square meter follow the same pattern among sites as shown in Fig. 2, only more exaggerated.

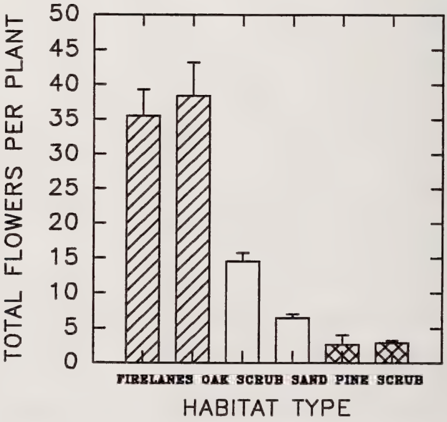


FIG. 2. Open flowers per plant in *Dicerandra frutescens* in two examples in each of three scrub habitat types.

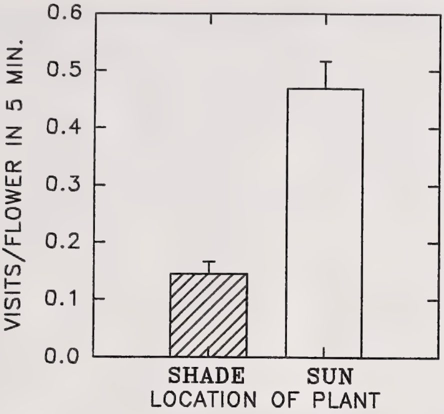


FIG. 3. Visits by *Exprosopa fasciata* to *Dicerandra frutescens* flowers that are shaded or in sun.

Visitation rates also differed markedly depending on plant microsite. Rates were nearly 3 times as high for plants in the sun during the 5-min watch as those shaded or during times under cloud cover (collectively "shade" see Fig. 3). Across all sites, sun/shade visits per flower were significantly different (one-way ANOVA, $F=34.2$, $df=1$, $p<0.0000$). Differences were also marked between sun and shade conditions within individual sites (data not shown).

Rates of bee fly visitation did not dramatically differ between plants supporting mainly cream-colored or mainly white-colored flowers. Flower visitation rates increased significantly with the number of white flowers ($r=0.68$, $p<0.01$), and to a lesser extent with the number of cream flowers ($r=0.28$, $p<0.01$). At any one time, the numbers of white and cream flowers were uncorrelated ($r=0.04$, $n=463$).

In analyses of variance, numbers of *E. fasciata* flies observed per watch and numbers of flowers visited per watch were each predicted by number of white flowers, number of cream flowers, population, and microhabitat. Date and time of the watch were not significant predictors. Between 52% and 61% of variation was explained. The most important predictor of pollinator activity was the number of white flowers. When analyses replaced population with vegetation type (firelanes, oak-hickory scrub, sand pine scrub), results were similar with firelane plants having the most visitation and sand pine scrub plants having the least. Among two-way interactions, vegetation type and microhabitat were significant ($p<0.05$), with sunny microhabitats in firelanes having the greatest visitation and with no advantage to sunny microhabitats in sand pine scrub.

Flower phenology—The pollination strategy of *D. frutescens* follows basic rules common to many other plants. In obligate, outcrossing, insect pollinated plants, the rewards must be large enough to attract and entrain pollinators, but these rewards must not be enough to satiate the insects on one plant. *Dicerandra frutescens* often produces simultaneously many flowers on one plant (Fig. 2), which has the advantage of easily attracting and training pollinators. Nonetheless, large flowering displays have the disadvantage that pollinators are likely to visit many flowers in succession on the same plant, which would seem to reduce the chances of cross fertilization.

Dicerandra frutescens, like many other plants, deals with this potential problem by a temporal separation of sexual function. Each flower opens in the morning and lasts 24 hours or less. In the morning, while the anthers are producing pollen, the stigma is curved downward and unlikely to come into contact with an insect. By afternoon the anthers are usually exhausted after repeated insect visits, and the stigma has moved upward so that it easily contacts insects landing on the flower. This system requires insects that are active through the day, and functions best if pollen is not efficiently groomed from the body (as is the habit of bees). Bee fly visitation rates are high, about 12–60 per flower based on our observations and assuming day-long activity, so in most cases, pollinator limitation of seed production is unlikely.

Over the course of the day the flowers on *D. frutescens* change from cream-colored to white, and we considered the possibility that this color change sends some kind of message to the insects, perhaps indicating that nectar production is decreasing following fertilization. We found no evidence of changes in visitation associated with color change, and we are inclined to think that this color change has no adaptive significance. The closely related *D. christmanii* Huck and Judd, which probably has the same pollination system (see below), remains cream-colored throughout the day.

Pollination mechanics—The bee-fly *Exprosopa fasciata* (Fig. 4) was the most abundant visitor (making about 95% of all visits, Table 2) and presumably is the most important pollinator of *D. frutescens.* Supplementary pollinator observations support the position of *E. fasciata* as primary pollinator, although large bees such as *Bombus* spp. and *Caupolicana electa* Cresson sometimes visit *D. frutescens,* and could be important pollinators when they are not nectar-robbing by chewing a hole in the corolla, thereby bypassing the anthers and stigma (Fig. 5). Visitation records strongly suggest that *D. frutescens* has specializations for excluding visitors other than *E. fasciata,* since other species of flowers blooming nearby at the same season (e.g., *Liatris* spp., *Balduina angustifolia* (Pursh) B.L. Robinson) have a great variety of visitors, including not only various species of bees and flies, but also wasps, beetles, and butterflies.

An examination of the mechanics of nectar presentation suggests ways in which *E. fasciata* may be accommodated and certain other visitors excluded. The long, elbowed corolla (Fig. 6 A–C) makes the nectar inaccessible to insects with short tongues. When a long-tongued bee fly or a bumble bee inserts its tongue into a flower, the tongue can be seen through the

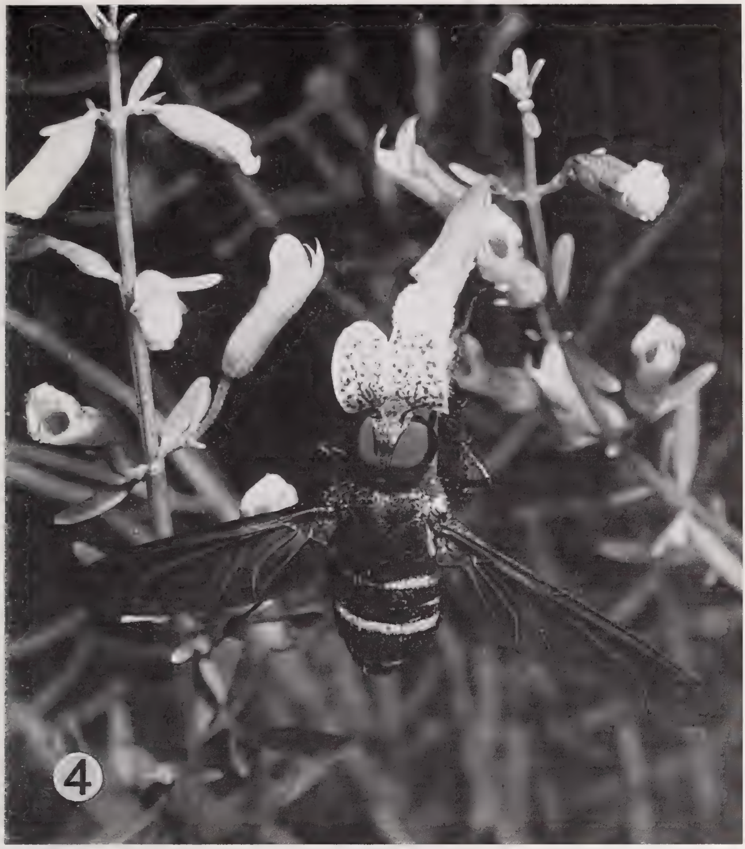


FIG. 4. The bombyliid fly *Exprosopa fasciata* on a flower of *Dicerandra frutescens.*

translucent corolla probing at the elbow of the flower, where a small amount of nectar is present. When the insect lands on the flower, however, most of the nectar, which is in the basal part of the corolla, becomes unavailable. This is because the weight of the insect on the landing area formed by the lower petals causes the flower to bend over more at the elbow, cutting off the passage that leads to the nectar at the base of the corolla. A large-headed, powerful insect, such as a large bee or bee fly, can push on the upper petal of the flower in the attempt to probe further into the flower. Pressure on the upper petal causes the corolla elbow to partially straighten (Fig. 7), allowing the insect to extend its tongue into the principal nectar supply. In this way, *D. frutescens* seems to limit its visitors to certain bees and the bee fly *E. fasciata* by requiring that the visitor have a long tongue and the ability to push on the upper petal with enough force to open the corolla. A flaw in this system is that the corolla must be free of the protective calyx below the elbow if the elbow is to bend, which makes the flower vulnerable to nectar-

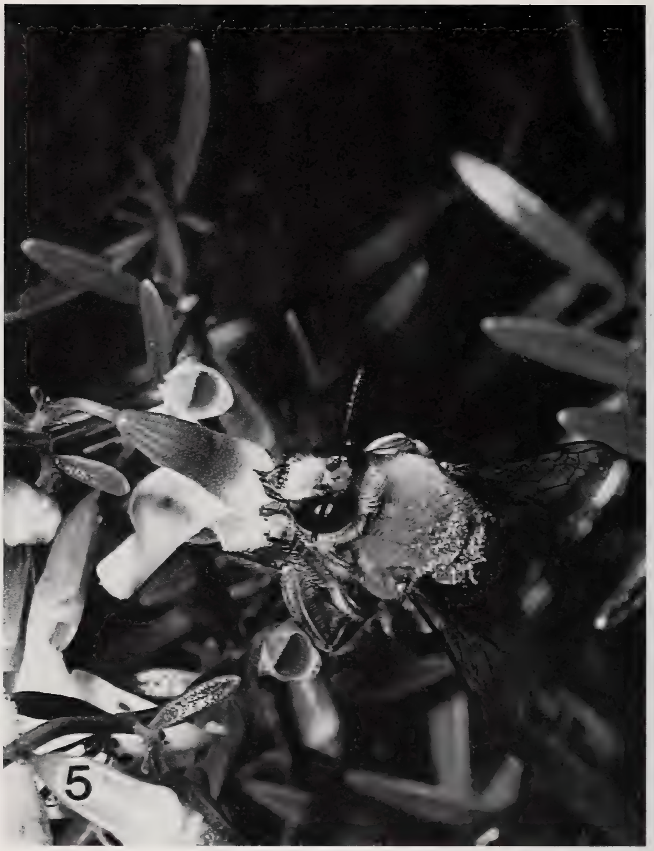


FIG. 5. The bee *Caupolicana electa* robbing nectar from *Dicerandra frutescens* by using its sharp labrum to split the corolla proximal to the elbow.

robbing bees, (such as *Caupolicana electa*) that pierce the corolla just below the elbow (Fig. 5).

Not all insects visit flowers for nectar: bees, bee flies, hover flies, beetles, and other insects collect pollen as well. Pollen-seeking insects are not likely to be attracted in numbers to *D. frutescens* because the pollen is concealed within the anthers. Inside the anthers the pollen is under pressure, and emerges in blobs from a slit when the spur on the anther is pressed down (Figs. 8,9). The main benefit from this remarkable mechanism may be to protect the pollen from desiccation, as suggested by Huck (1987), but a secondary benefit is that the pollen is relatively safe from small bees that could take the pollen without coming into contact with the stigma. The halictid bees *Dialictus tarponensis* Mitchell, *D. tegularis* (Robertson), and *Augochlorella* sp. are frequent pollen robbers on *Dicerandra frutescens* (Table 2), but we have not seen them pushing down on the anther spurs, and they probably collect pollen that failed to adhere to a larger insect that visited

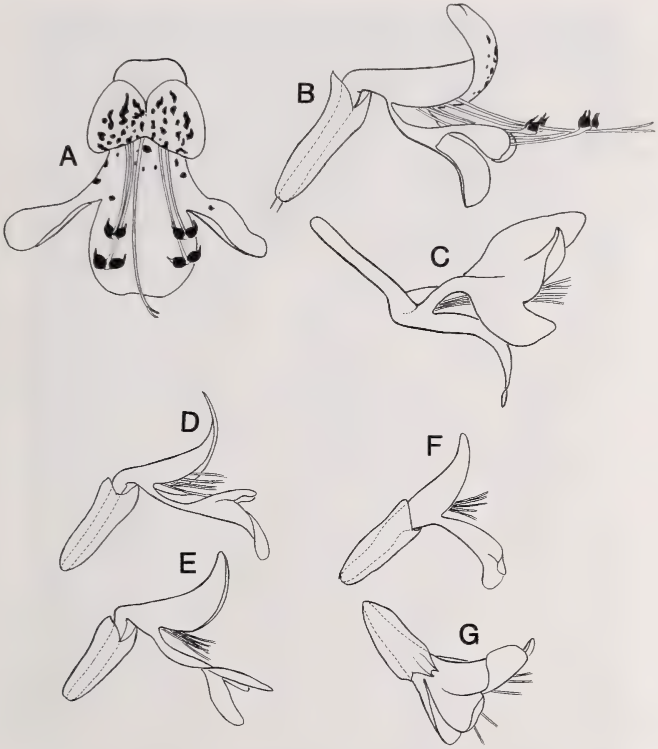


FIG. 6. Flowers of *Dicerandra* species. A–C: *D. frutescens*; D: *D. cornutissima;* E: D. *christmannii*; F–G: *D. immaculata.*

previously. Some bee-flies are proficient at manipulating anthers to obtain pollen (Deyrup, 1988), and we occasionally observed *E. fasciata* hanging from a flower, raking pollen from the anthers, using a set of glandular hairs on the front tarsi. *Exprosopa fasciata* is not a regular pollen feeder on *D. frutescens*; perhaps only a few individuals learn to deliberately depress the anther spurs.

There is evidence that *D. frutescens* is adapted for fly pollination rather than bee pollination. The anthers are positioned so that they deposit pollen on the underside of the abdomen of the visiting insect (Fig. 9). Flowers that are adapted for bee pollination tend to deposit pollen on the back or sides of the bee, since female bees easily groom off and utilize pollen that is deposited on the venter. This distinction is particularly relevant to *D. frutescens,* since the pollen deposited soon after the flowers open must persist on the insect for several hours before the stigmas are in the receptive position.

Pollination in other Dicerandra *species*—Hypotheses dealing with supposed morphological adaptations can be tested by comparative studies (Jak-

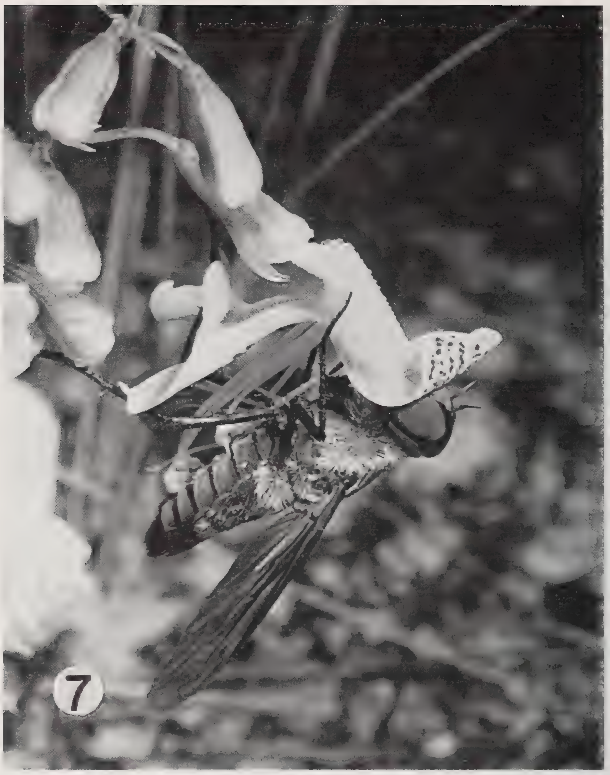


FIG. 7. *Exprosopa fasciata* on flower of *Dicerandra frutescens,* showing the partial straightening of the corolla elbow as the fly pushes on the upper petal. Anther spurs are depressed and the stigma is not touching fly.

sic, 1981), and the hypothesis that *D. frutescens* is specialized for pollination by *E. fasciata* might be tested by correlating floral morphology and pollination in other species of *Dicerandra.* We have not done such a study, but there are some useful preliminary observations. *Dicerandra christmanii,* which has a structure identical to *D. frutescens* (Fig. 6E), is said to be visited "almost exclusively" by *E. fasciata* (Huck et al., 1989). We briefly observed a patch of *D. cornutissima* Huck near Ocala (Marion County); both bees and flies were visiting the flowers. During a period of about an hour individuals of *Bombus pennsylvanicus* (Degeer) visited 26 flowers and 6 plants, while *E. fasciata* visited 129 flowers and 30 plants. The floral structure of *D. cornutissima* Huck (Fig. 6D) is similar to *D. frutescens.* We also briefly studied *D. immaculata* Lakela (6F–G) near Fort Pierce (St. Lucie County). Flowers were visited by bumble bees (*Bombus impatiens* Cresson, *B. pennsylvanicus*), honeybees (*Apis mellifera* Linnaeus), halictid bees (*Dialictus* sp., *Augochloropsis* sp.), bombyliid flies (*Bombylius mexicanus* Wiedemann), syrphids (*Eristalis vinetorum* [Fabricius]), and skippers (*Urbanus*

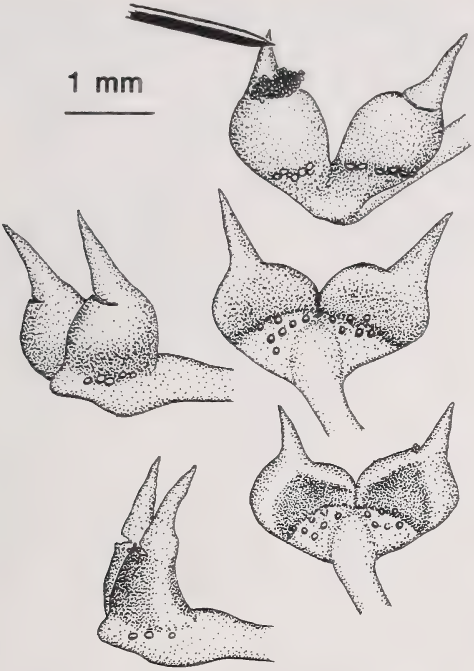


FIG. 8. *Dicerandra frutescens,* mechanism for dispensing pollen. Top three drawings are pollen-filled anthers, bottom two drawings are anthers that have released their pollen.

proteus Linnaeus and unidentified species). During a short watch the following numbers of flowers were visited: *B. pennsylvanicus*: 109, *B. impatiens*: 10, *E. vinetorum*: 6, *B. mexicanus*: 5, skippers: 5, halictids: 4, *A. mellifera*: 1. These observations, supported by longer periods of undocumented observation of numerous bumble bees moving rapidly over large numbers of flowers, indicate that bees are primary polinators of *D. immaculata.* No *E. fasciata* were seen on the plants, although 14 *E. fasciata* were seen feeding on flowers of *Polygonella* spp. at the same site.

This preliminary survey of *Dicerandra* species allows some correlation between flower visitors and flower morphology. *Dicerandra christmanii* and *D. cornutissima,* which are most frequently visited by *E. fasciata,* have flowers that are structurally similar to *D. frutescens. Dicerandra immaculata,* which is most frequently visited by bumble bees, has flowers that are structurally different from *D. frutescens.* In the latter species the corolla is shorter, lacks a flexible elbow, and is largely contained inside the calyx (Fig. 6 F–G). An important result of this arrangement is that nectar-robbing is both more difficult (because most of the corolla is protected by the calyx) and less attractive relative to "legitimate" entry (because the corolla is short and there is no trick to extracting the nectar). The anthers and stigma of *D. immaculata* are usually splayed out laterally, so pollen is deposited on the

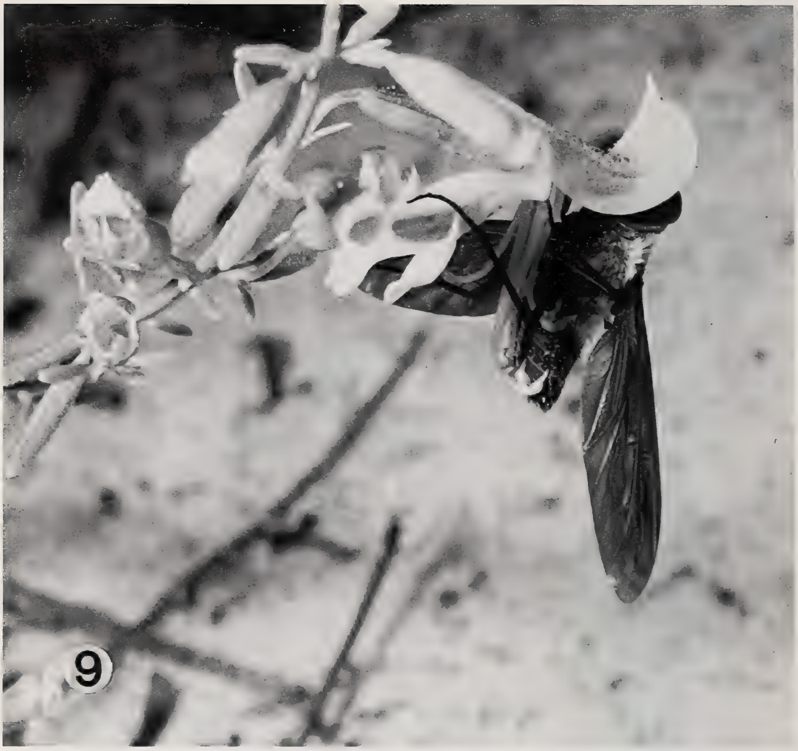


FIG. 9. *Exprosopa fasciata,* ventral view, showing contact position of *Dicerandra frutescens* anthers.

sides rather than the venter of the bee. There is, however, nothing about the flower that would appear to exclude *E. fasciata,* unless the abundant aggressive bees tend to displace the flies.

Pollination specialization and extinction risk— All our evidence seems to show that *D. frutescens* is highly dependent upon a single pollinator, *E. fasciata.* Such extreme specialization does not necessarily contribute to the rarity of a species or make it particularly vulnerable to extinction. If, however, the pollinator is dependent on the plant, the populations of the two species can become trapped in a downward spiral to extinction. If the pollinator is not dependent on the plant, but is rare or local for other reasons, the abundance and distribution of the plant may come to reflect this.

These situations do not apply to *E. fasciata.* It is a common species in open sandy areas, with a range extending from New Hampshire and Wyoming south to Florida and New Mexico (Painter and Painter, 1965). It visits a great variety of flowers; at the Archbold Biological Station we have found it feeding on the following species: Asteraceae: *Garberia heterophylla* (Bartram) Merr.& Harp., *Liatris tenuifolia* Nuttall, *Balduina angustifolia, Bidens*

alba (Linnaeus), *Pityopsis graminifolia*(Michaux) Nuttall, *Palafoxia feayi* A. Gray, *Solidago chapmanii* Torrey & Gray, *Euthamia minor* (Michaux) Greene, *Heterotheca subaxillaris* (Lamarck) Britt. & Rusby; Chrysobalanaceae: *Licania michauxii* Prance; Polygonaceae: *Polygonella gracilis* (Nuttall) Meisner, *P. fimbriata* var. *robusta* (Small) Horton, *P. polygama* (Ventenant) Engelman & Gray, *Eriogonum floridanum* Small; Apiaciae: *Eryngium cuneifolium* Small; Brassacaceae: *Warea carteri* Small; Fabiaceae: *Dalea feayi* (Chapman) Barneby. The larval biology of *E. fasciata* is unknown. We have frequently seen adults ovipositing in open sand. Judging by the size of the adult, its habitat preference, and its geographic range, it seems likely that the larvae feed on the larvae of large root-feeding scarabs that are abundant in sandy areas.

Although there is always the possibility that *E. fasciata* was a rare species at some time in the past (a hypothesis not easily tested!), judging by the current status of *E. fasciata, D. frutescens* is not limited by its specialized relationship with its pollinator. On the contrary, it has achieved a major goal of pollination strategy by inducing a common, generalist insect to act as if it were a specialist.

The scrub *Dicerandra* species are remarkable both for their miniscule, widely disjunct geographic ranges (Huck, 1987; Huck et al., 1989) and for their curious trigger-action anthers. It is tempting to try to see a correlation between the rarity of the species, and the peculiar anthers which, as Huck noted (1987), allow extreme specialization for one kind of pollinator. The evidence, however, is that scrub *Dicerandra* species are rare because they occur only in open microsites within Florida scrub on particular yellow sand soil types (Menges, 1992). Most areas that are edaphically appropriate are occupied by sandhill habitat, a habitat that may burn more frequently than perennial *Dicerandra* species can tolerate. Scrub on yellow sand tends to become very dense after 30 years or so, eventually crowding out *Dicerandra* (Menges, 1992).

The specialization of *D. frutescens* for early postfire scrub is paralleled by pollinator visitation data. Visitation occurs most often to plants with many flowers, which tend to occur in populations recently disturbed by fire or mechanically. In addition, sunlit microsites have greater *Exprosopa* visitation, even within generally open areas (hence the significant interaction between population and microsite on visitation rates). *Diecerandra frutescens* populations in scrub undisturbed for decades face a series of limitations on fecundity: poor flower production (Fig. 3), relatively low rates of pollinator visitations (Fig. 2, Table 3, and ANOVAs), and poor fruit set percentages (Menges, unpublished data). Because adult plants are short-lived, poor fecundity contributes to overall weak demographic performance for *D. frutescens* in undisturbed scrub, and its subsequent dependence on landscapes that are periodically burned. These landscapes currently are being converted to human uses or are being fragmented and fire-suppressed (Christman & Judd

1990, Peroni & Abrahamson 1985), accelerating the decline of *D. frutescens* and other scrub species.

Scrub *Dicerandras* as a group may well be vanishing relics of a time when sandhill was much less prevalent and open scrub on yellow sand was much more prevalent. If ecologists had been around at such a time, or if the genus were presently widespread, abundant, and speciose, the anther trigger mechanism would undoubtedly be invoked as an evolutionary breakthrough, at least partially responsible for the success of the group. As it is, the remarkable pollination mechanism of *Dicerandra* seems trapped in a declining taxon. It is some comfort that attempts to preserve the last remaining populations of species such as *D. frutescens* are not likely to be thwarted by a lack of appropriate pollinators.

Acknowledgments—We gratefully acknowledge our field assistants Noreen Gallo Barlow and Robert Shumate, who helped us with the flower watches at the Archbold Biological Station. Nancy Deyrup prepared the photographs for publication. Stephen Deyrup assisted with observations of *D. cornutissima* and Dr. John Fitzpatrick assisted with observations of *D. immaculata*. The late Dr. George Eickwort identified the bees *Dialictus tarponensis* and *D. tegularis*. Marcia Hestand typed the manuscript.

LITERATURE CITED

Abrahamson, W. G., A. F. Johnson, J. N. Layne, and P. A. Peroni. 1984. Vegetation of the Archbold Biological Station, Florida: an example of the southern Lake Wales Ridge. Florida Scient. 47: 209–250.

Christman, S. P., and W. S. Judd. 1990. Notes on plants endemic to Florida scrub. Florida Scient., 53: 209–250.

Deyrup, M. 1988. Pollen-feeding in *Poecilognathus punctipennis* (Diptera: Bombyliidae). Florida Entomol. 71: 597–605.

Eisner, T., K. D. McCormick, M. Sakaino, M. Eisner, S. R. Smedley, D. J. Aneshansley, M. Deyrup, R. L. Myers, and J. Meinwald. 1990. Chemical defense of a rare mint plant. Chemoecology 1: 30–37.

Huck, R. B. 1987. Systematics and evolution of *Dicerandra* (Labiatae). Phanerogr. Monogr. 19: 1–343.

Huck, R. B., W. S. Judd, W. M. Whitten, J. D. Skean, Jr., R. P. Wunderlin, and K. R. Delaney. 1989. A new *Dicerandra* (Labiatae) from the Lake Wales Ridge of Florida, with a cladistic analysis and discussion of endemism. Syst. Bot. 14: 197–213.

Jasic, F. M. 1981. Recognition of morphological adaptation in animals: the hypothetico-deductive method. Bioscience 31: 667–670.

McCormick, K. D., M. A. Deyrup, E. S. Menges, S. R. Wallace, J. Meinwald, and T. Eisner. 1993. Relevance of chemistry to conservation of isolated populations: the case of volatile leaf components of *Dicerandra* mints. Proc. Nat. Acad. Sci. USA 90: 7701–7705.

Menges, E. S. 1992. Habitat preferences and response to disturbance for *Dicerandra frutescens*, a Lake Wales Ridge (Florida) endemic plant. Bull. Torrey Bot. Club 119: 308–313.

Painter, R. J., and E. M. Painter. 1965. Family Bombylilidae. Pp. 407-446 *in:*Stone, A., C. W. Sabrosky, W. W. Wirth, R. H. Foote, and J. R. Coulson,(eds.) A catalog of the Diptera of America north of Mexico. U.S. Govt. Printing Office, Washington, D.C.

Peroni, P. A., and W. G. Abrahamson. 1985. Vegetation loss on the southern Lake Wales Ridge. Palmetto 5: 6–7.

Smedley, S. R., K. D. McCormick, and T. Eisner. 1990. Interaction of *Pyrausta panopealis*

(Pyralidae) with a newly-reported host, the endangered mint *Dicerandra frutescens* (Labiatae). J. Lepidop. Soc. 44: 156–162.

WUNDERLIN, R. P. 1982. Guide to the vascular plants of central Florida. University of South Florida University Presses, Tampa, FL. 472 pp.

Florida Scient. 60(3): 143–157. 1997
Accepted: November 6, 1996.

THE EFFECTS OF AZADIRACHTIN ON LARVAL STAGES OF THE OAK TOAD, *BUFO QUERCICUS* (HOLBROOK)

Fred Punzo

Department of Biology, University of Tampa, 401 W. Kennedy Blvd., Box 5 F,
Tampa, Florida 33606, USA

Abstract: *I conducted a series of experiments on the effects of azadirachtin (AZA) on tadpoles of the oak toad,* Bufo quercicus. *These are the first data available on the effects of this pesticide on an amphibian species.* LC_{50} *values (96-hr) for various developmental stages exposed to 0.5 mg/L AZA were as follows: 4.41 (stage 12), 4.39 (stage 16), 6.12 (20), 11.34 (24), and 19.62 (30). Percent mortality of various larval developmental stages increased with increasing concentrations of AZA . The highest mortality rate (44%) was recorded for stage 12 tadpoles exposed to 0.50 mg/L AZA. An AZA concentration of 0.30 mg/L had no significant effect on mortality for any developmental stage. Exposure to concentrations of 0.40 and 0.50 mg/L AZA resulted in a significant decrease in percent fertilization success of* B. quercicus *eggs, and a marked reduction in swimming speed of stage 24 tadpoles. At a concentration of 0.50 mg/L, food consumption by stage 24 tadpoles was significantly reduced. The potential hazard to amphibian populations posed by neem-based compounds is discussed.*

Azadirachtin (AZA) is a triterpenoid derived from the tree, *Azadirachta indica* (Meliaceae) (Isman et al., 1990). This tree is native to India and Burma, and has more recently been introduced into other areas of the Indo-Malaysian region as well as southern Europe and Australia. Neem extracts from leaves and seeds containing AZA have been shown to exhibit potent antifeedant and growth disrupting effects on insects (Mordue and Blackwell, 1993). Over the last fifteen years these compounds have been used with a great deal of success in the control of numerous stored product and phytophagous insects. Ingestion or topical treatment with AZA interferes with ecdysone synthesis resulting in delayed or abnormal molting and a suppression of normal feeding behavior (Jacobson, 1988; Schmutterer, 1990). Its relative success, low persistence, and apparent low toxicity to beneficial insects has led some researchers to hail AZA as another miracle pesticide. As a result, the systematic use of AZA-based products in agroecosystems worldwide has increased markedly over the last decade (Ali, 1987; Mordue and Blackwell, 1993) .

However, little information is available on the effects of AZA on vertebrates (Punzo, 1997). Wan and co-workers (1996) reported the LC_{50} values for AZA and other neem-based compounds on juvenile salmon. Ingestion of neem leaves caused gastric and respiratory problems in sheep and guinea pigs (Ali, 1987; Ali and Salih, 1982). To date, there have been no studies on the effects of AZA on amphibians.

In view of the increasingly widespread use of neem-based pesticides, the recent concern over worldwide declines in amphibian populations (Baringa, 1990; Blaustein et al., 1994; Blaustein and Wake, 1995), and the high sensitivity of amphibians to environmental contaminants (Cooke, 1981; Punzo, 1993a, 1993b), I examined the effects of AZA on embryos and larval stages of the oak toad, *Bufo quercicus* . Specifically, I determined levels of toxicity (LC_{50}) for various tadpole developmental stages, as well as the effects of AZA on mortality, percent fertilization success, swimming speed and food consumption.

MATERIALS AND METHODS—Commercially available neem seed extract containing AZA (Neemix 4.5, 99% pure) was obtained from W. R. Grace and Co. (Columbia, Maryland).

All animals used in this study were reared in the laboratory from eggs and adults originally collected at Myakka River State Park (Sarasota Co., FL). They were maintained in my laboratory as previously described by Punzo (1995). Dechlorinated tap water (DTW) was used as exposure / control water for all experiments (Punzo, 1993a). DTW was examined at 24-hr intervals using a Hach chemical test kit (Hach Chemical Co., St. Louis, Missouri), and atomic absorption analysis was used to determine and monitor water quality throughout the testing procedure (Punzo, 1993b). Water quality parameters of DTW were as follows (Mean ± SD, N = 27) : pH 7.21 ± 0.12; conductivity, 719 ± 28.5 umhos; total hardness, 349.6 ± 11.9 mg / L as $CaCO_3$; total alkalinity, 273.6 ± 14.7 mg / L as $CaCO_3$; nitrite, 0.006 ± 0.001 mg / L ; nitrate, 0.81 ± 0.14 mg / L ; ammonia, 0.34 ± 0.01 mg / L ; calcium, 83.9 ± 3.7 mg / L ; copper, 0.003 ± 0.0001 mg / L ; and magnesium, 30.9 ± 1.4 mg / L .

Toxicity tests—I conducted a series of 96-hr acute toxicity tests on various larval developmental stages using the same protocol as that described by Wan and co-workers (1988). Larval stages were identified according to Gosner (1960). For each toxicity test, 25 tadpoles were placed in an aerated one-liter glass container containing DTW and exposed once to a 0.5 mg / L concentration of AZA. This concentration was chosen a priori as a result of previous work done on salmon (Wan et al., 1988), levels of AZA reported from aquatic habitats in the field, and preliminary observations made on *B. quercicus* tadpoles in my laboratory. In all experiments, AZA was introduced into the DTW using 25 ml of acetone as the carrier (Isman et al., 1990). An equivalent amount of acetone without AZA was used in experiments on controls . All tests were conducted in an environmental chamber (Percival Model I-37, Boone, Iowa) at 21°C under a 12L : 12D photoperiod regime. Duplicate tests were conducted for controls and each concentration of AZA. The DTW was analyzed several times to monitor water quality and AZA content using the HPLC procedure described by Sundram and Curry (1993). Cumulative tadpole mortality was recorded daily and LC_{50} values were determined using probit analysis (Finney, 1971).

I also used the same protocol to determine the effects of a 96-hr exposure period to different concentrations of AZA (0, 0.30, 0.40, or 0.50 mg / L) on the survival capacity of various developmental stages of *B. quercicus* (stages 12—late gastrula; 16—neural tube formation; 20—gill circulation and heart beat; 24—operculum development; 30—limb buds). One hundred tadpoles were tested for each condition of AZA concentration and developmental stage. Data were expressed as percent mortality.

Effects on fertilization—Each experimental condition used the sperm and eggs from a single male and female, respectively, and was replicated five times. Adult males and females were allowed to breed in the laboratory. The females were injected with pituitary extracts as described by Johnson and Volpe (1973) prior to interaction with a male to ensure the production of eggs. When an adult male was observed in amplexus with a female, the pair was transferred to a one-liter bowl containing DTW (20°C) plus a specific concentration of AZA (0.30, 0.40 or 0.50 mg / L), until the eggs and sperm had been released by the female and male, respectively. Control gametes were exposed to DTW and acetone without AZA as described above. The adults were then removed from the bowl. Preliminary observations had shown that fertilization is completed within 2 hr. This could be verified by the presence of a completely formed fertilization membrane (Johnson and Volpe, 1973). Following a 2-hr period, eggs were washed with DTW and observed under a Unitron dissecting microscope. Cleavage was used as the criterion that fertilization had taken place. Percent fertilization was determined for all test conditions as reported by Punzo (1993b). Data were analyzed with a Chi Square contingency procedure utilizing Yate's correction for discontinuity (Sokal and Rohlf, 1981).

Effect on swimming speed—All experiments were conducted over a two-day period on tadpoles that had just reached stage 24 of development (Gosner, 1960). The apparatus and protocol used to determine swimming speed have been described in detail in Punzo (1992). To summarize, individual tadpoles were subjected to swimming trials in a black Plexiglass runway (140 × 10 × 16 cm). A sliding door was placed 20 cm from one end of the runway forming a start chamber. A plastic container provided with holes (feeding chamber) was placed at the other end containing tadpole food pellets (Carolina Biological Supply, Burlington, NC) which allowed the animals to feed after each swimming trial. The entire runway was submerged in aerated DTW for all trials. Water temperatures in the runway were maintained between 20–22°C using a Jewel Model 1903 thermostat (Carolina Biological Supply). All swimming trials were conducted under cool, fluorescent lighting conditions. All tadpoles used in these experiments were housed individually in one-liter bowls provided with DTW and various concentrations of AZA (0.30, 0.40, or 0.50 mg / L) for a period of 96 hr prior to testing in the runway. Controls (0 mg/L AZA) were treated as described previously. Twenty tadpoles were subjected to each test condition.

Prior to swimming trials, all tadpoles were allowed to explore (habituate to) the runway for 30 min on two consecutive days. Each tadpole was subjected to five swimming trials per day for two days. All animals were deprived of food for 24 hr prior to testing. For each trial, an individual tadpole was placed in the start chamber for a period of one min. The sliding door was then opened and the tadpole was gently tapped on the end of its tail with a glass rod. The tadpole was then allowed to swim the length of the runway and feed at the food chamber for 30 sec. The animal was then returned to the start chamber for a period of one min before the start of the next swimming trial. The length of time required to swim the length of the runway (140 cm) (excluding feeding time) was recorded with a stopwatch behind a one-way mirror to minimize any disturbance to the animals. Data were analyzed using a one-way ANOVA followed by Scheffe F test comparisons (Sokal and Rohlf, 1981).

Effect on food consumption—Experiments were also conducted to assess the effects of AZA on food consumption in *B. quercicus* tadpoles. The protocol used to measure this parameter has been described in detail by Warkentin (1992). To summarize, ten groups, each consisting of five tadpoles (stage 24, head—body length, HBL : 6–9 mm), were initially subjected to a 0.01% carbon powder suspension (Sigma Chemical Co., St. Louis, Missouri) in aerated DTW for a period of 20 min which establishes a clearly delineated black band in their gut contents. This is used to denote the beginning of a specific feeding trial. For feeding rate determinations, individual tadpoles were transferred to one-liter aerated glass bowls provided with DTW, food, and a specific concentration of AZA (0, 0.30, 0.40 or 0.50 mg / L) (N = 20 for each test condition). Each bowl contained boiled lettuce as a food source. Following a two-hr feeding period, each tadpole was anesthetized in a solution of 0.4% tricaine methylsulphonate (Sigma Chemical Co.) and preserved in 10% buffered formalin for subsequent dissection. Alimentray tracts were then removed via dissection in order to determine food consumption (volume of food ingested). The diameter of the gut was measured for an additional 20

TABLE 1. LC_{50} values (mg/L) for various stages of *Bufo quercicus* tadpoles exposed for 96 hr to 0.5 mg/L azadirachtin. Larval stages identified according to Gosner (1960). Numbers in parentheses represent 95% confidence limits (see text).

Stage	LC_{50} (mg/L)
12	4.41 (3.9–4.6)
16	4.39 (3.7–4.5)
20	6.12 (5.8–6.2)
24	11.34 (10.3–11.7)
30	19.62 (17.9–20.4)

tadpoles (stage 24) using a dissecting microscope. Gut diameter was found to scale with size as: $d = 0.136 + 0.028 \times HBL$ ($r = 0.824$, $p < 0.01$). I used this regression equation to estimate gut diameter for each tadpole from its HBL. The length of the gut anterior to the carbon band filled with food multiplied by r^2 gives a reliable value for the volume of food ingested (expressed in ml food consumed) Warkentin, 1992). Data were analyzed using a Kolmogorov-Smirnov test (Sokal and Rohlf, 1981).

RESULTS—The LC_{50} values for *B. quercicus* tadpoles exposed to 0.5 mg/L AZA for 96 hr are listed in Table 1. It is apparent that earlier developmental stages (12–16) are more susceptible to AZA than later stages. In addition, tadpoles did not exhibit any apparent disorientation or production of mucous in response to AZA.

The effects of various concentrations of AZA on the survival capacity of *B. quercicus* are shown in Table 2. A Chi Square contingency test showed that mortality was significantly higher ($p < 0.01$) at 0.50 mg/L AZA than at lower concentrations. Again, earlier developmental stages were more sensitive to this insecticide. At 0.50 mg/L AZA, mortality rates decreased makedly from 44% for stage 12 tadpoles, to 16% for stage 30 tadpoles.

Exposure of gametes to 0.30 mg/L AZA had no adverse effect on fertilization success as compared to controls (93 vs. 90%, Table 3). At 0.40 mg/L, percent fertilization decreased significantly (77%). The effect was more pronounced at 0.50 mg/L (58%).

Exposure of stage 24 tadpoles to 0.30 mg/L AZA had no effect on swimming speed (Table 4). However, a concentration of 0.40 mg/L caused

TABLE 2. The effects of various concentrations of azadirachtin (AZA) on percent mortality in different developmental stages of *Bufo quercicus* tadpoles. N = 100 tadpoles.*

	Concentration of AZA (mg/L)			
Stage	0	0.30	0.40	0.50
12	7	11	24	44
16	5	7	17	29
20	6	6	12	34
24	7	10	10	26
30	5	5	8	16

* N = 100 tadpoles/AZA concentration/developmental stage (see text).

TABLE 3. Effects of various concentrations of azadirachtin (AZA) on percent fertilization success of *Bufo quercicus* eggs. Values followed by different letters are significantly different using a Chi Square analysis ($p < 0.01$) (see text).

Concentration of AZA (mg/L)	Total Number of Eggs	Number Fertilized	Percent Fertilized
0	967	901	93 a
0.30	738	667	90 a
0.40	861	659	77 b
0.50	753	440	58 c

a significant decrease in swimming speed (Duncan multiple range test, $p < 0.05$). This effect was more pronounced when tadpoles were exposed to a concentration of 0.50 mg/L ($p < 0.01$).

The effects of AZA on food consumption are shown in Table 4. Control animals consumed a mean volume of 0.44 ml of food. Exposure to 0.30 and 0.40 mg/L AZA had no effect on food consumption. Tadpoles exposed to an AZA concentration of 0.05 mg/L, however, exhibited a significant reduction in the amount of food ingested.

DISCUSSION—The results of this study clearly indicate that AZA can have significant adverse effects on embryos and larval stages of this amphibian. Furthermore, the concentrations used in these experiments (0.3, 0.4 and 0.5 mg / L) are well within the range of levels reported for this insecticide in ponds, lakes and streams worldwide (Schmutterer, 1985; Grant and Schmutterer, 1987). For example, AZA concentrations of 0.2–0.5 mg/L have been found in numerous lakes in India and other parts of Asia. Sediment concentrations of 0.25–0.52 mg/L are not uncommon in lakes and ponds associated with agroecosystems in the southeastern United States (Jacobson, 1988).

The mode of action of AZA has been intensively studied only in insects. Despite almost two decades of research, the specific mechanisms for its actions are still not fully understood (Mordue and Blackwell, 1993). It is

TABLE 4. Effects of various concentrations of azadirachtin (AZA) (mg/L) on the swimming speed (in sec) and food consumption (ml) of *Bufo quercicus* tadpoles (stage 24). Values represent means (± S.D.). Levels of significance computed using a Duncan multiple range test (* $p < 0.05$; ** $p < 0.01$) for data on swimming speed; a Kolmogorov–Smirnov test (* $p < 0.05$) was used for the data on food consumption (see text).

Concentration of AZA (mg/L)	Swimming Speed (sec)	Food Consumption (mL)
0	148.4 (16.8)	0.44 (0.11)
0.30	144.6 (21.3)	0.51 (0.09)
0.40	179.2 (19.4)*	0.47 (0.12)
0.50	273.8 (24.1)**	0.37 (0.04)*

well known that AZA inhibits or terminates feeding activities in insects. It has been suggested that AZA somehow blocks neural input (decreases the rate of depolarization) from insect chemoreceptors, especially the gustatory sensilla (Waladde, 1989). However, the exact mechanism remains unknown. AZA also interferes with normal endocrine function. Insects exposed to AZA exhibit modified hemolymph ecdysteroid titres. This results in delayed ecdysis or abnormal molting patterns. AZA-treated insects frequently die during apolysis or before completing ecdysis (Barnby and Klocke, 1990). Thus, AZA either interferes with the normal synthesis of steroids and / or modifies steroid receptors in some way.

Data from this study show that exposure to AZA reduced the fitness of *B. quercicus* . The LC_{50} value reported for stage 12 tadpoles (4.41 mg/L) compares favorably with that reported for juvenile Pacific salmon (4.0) by Wan and co-workers (1996). Concentrations of 0.40 and 0.50 mg/L AZA increase mortality in various developmental stages. Mortality among various stages of control tadpoles was low, ranging from 5–7%. This range increased from 10–44% for those tadpoles exposed to 0.40–0.50 mg/L AZA.

Exposure to AZA also decreased fertilization success in this species. With respect to fertilization, this action of AZA is similar to that reported for a variety of heavy metals and organic pesticides in amphibians and other vertebrates (Clarkson et al., 1983; Goyer, 1986; Power et al., 1989). This decrease in fertilization success was apparently not the result of a decrease in sperm motility. Based on qualitative microscopic observations, sperm in water treated with AZA seemed to exhibit normal morphology and the same degree of motility as sperm in DTW. However, further experiments should be conducted in order to more accurately quantify any differences in degree of motility that may exist.

The swimming speed of tadpoles also decreased significantly when they were exposed to 0.40 and 0.50 mg/L AZA. This could result in a decreased ability to escape mobile predators, resulting in higher mortality rates and reduced overall fitness. The reduction in food consumption associated with exposure to AZA would result in slower growth rates and smaller adult size. This is in general agreement with previous studies which showed that sublethal concentrations of stressors such as pH and heavy metals reduced swimming speed and ingestion rates in salamanders (Griffiths, 1993 ; Kutka, 1994) and hylid tadpoles (Jung and Jagoe, 1995). Frequently, a combination of stressors (including thermal stress, pH, pollutants) can act synergistically in reducing fitness in amphibian populations (Carey, 1993). In addition, long-term stress resulting from pollutants can result in reduced fitness and declining populations resulting from immunosuppression (Carey and Bryant, 1995). Chronic sublethal doses of an insecticide such as AZA could have similar long range effects on amphibian populations.

In conclusion, AZA can significantly reduce fitness in *B. quercicus* as well as the wolf spider, *Schizocosa episina* (Aranea : Lycosidae) (Punzo, 1997). Spiders have been shown to be important biocontrol agents in agroecosystems (Riechert and Lockley, 1984). Toads are important insectivores as well (Punzo, 1995). Advocates of AZA and other neem-based products have praised its relatively low toxicity to non-target species. In view of the results from this study, we need to study the effects of AZA on aquatic and terrestrial vertebrates with more scrutiny. In addition, further research should be conducted with the aim of identifying specific physiological and molecular processes affected by AZA in vertebrates.

ACKNOWLEDGEMENTS—I would like to thank T. Punzo and B. Keller for technical assistance in the laboratory and field collection of specimens. I thank B. Garman for consultation on statistical analyses, J. Smith, R. Seigel and anonymous reviewers for comments on an earlier draft of the manuscript, and R. Stewart for assistance with atomic absorption analyses of water samples. I thank the W.R. Grace Co. (Maryland) for AZA samples. I am also grateful to the Florida Department of Environmental Protection (Division of State Parks) for permission to collect toads (Permit # 4-96-11). A Faculty Development Grant from the University of Tampa made much of this work possible.

LITERATURE CITED

ALI, B. H. 1987. The toxicity of *Azadirachta indica* leaves in goats and guinea pigs. Vet. Human Toxicol. 29 : 16–23.

——— AND A. M. SALIH. 1982. Suspected *Azadirachtin indica* toxicity in sheep. Vet. Rec. 111 : 494–499.

BARINGA, M. 1990. Where have all the froggies gone? Science 247 : 1033–1034.

BARNBY, M. A. AND J. A. KLOCKE. 1990. Effects of azadirachtin on levels of ecdysteroids and prothoracotropic hormone-like activity in *Heliothis viriscens* (Noctuidae). J. Insect Physiol. 36 : 125–131.

BLAUSTEIN, A. R.AND D. B. WAKE. 1995. The puzzle of declining amphibian populations. Sci. Amer. 272 : 56—61.

———, D. B. WAKE,AND W. P. SOUSA. 1994. Amphibian declines: judging stability, persistence, and susceptability of populations to local and global extinctions. Concerv. Biol. 8 : 60—71.

CAREY, C. 1993. Hypothesis concerning the causes of the disappearance of boreal toads from the mountains of Colorado. Conserv. Biol. 7 : 355–362.

——— AND C. J. BRYANT. 1995. Possible interrelations among environmental toxicants, amphibian development, and decline of amphibian populations. Environ. Health Perspec. 103 (Suppl. 4) : 13–17.

CLARKSON, T. W., G. NORDBERG, AND P. R. SAGER. 1983. Reproductive and Developmental Toxicity of Metals. Plenum Press, New York, NY

COOKE, A. S. 1981. Tadpoles as indicators of harmful levels of pollution in the environment. Environ. Pollut. (Ser. A) 25 : 123–133.

FINNEY, D. J. 1971. Probit Analysis. Cambridge University Press, London.

GOSNER, K. L. 1960. A simplified table for staging anuran embryos and larvae with notes on identification. Herpetologica 16 : 183–190.

GOYER, R. A. 1986. Toxic effects of metals. Pp. 582–635. *In*: KLASSEN, C., M. AMDUR AND J. DOULL (eds.), Toxicology. Macmillan Pub. Co., New York, NY

GRANT, I. F. AND H. SCHMUTTERER. 1987. Effects of aqueous neem seed kernel extracts on ostracod (Class Crustacea) development and population density in lowland rice fields. Pp. 591–610. Proc. 3rd Int. Neem Conf. (H. Schmutterer and K. R. Ascher, eds.). GTZ Eschorn, Germany.

GRIFFITHS, R. A. 1993. The effect of pH on feeding behavior in newt larvae (*Triturus* : Amphibia). J. Zool., Lond. 231 : 285–290.

ISMAN, M. B., O. KOUL, A. LUCZYNSKI,AND J. KIMINSKI. 1990. Insecticidal and antifeedant bioactivities of neem oils and their relationship to azadirachtin content. J. Agric. Food Chem. 38 : 1406–1411.

Jacobson, M. 1988. Focus on Phytochemical Pesticides. Vol. 1. The Neem Tree. CRC Press, Boca Raton, FL

Johnson, L. G. and E. P. Volpe. 1973. Patterns and Experiments in Developmental Biology. W. C. Brown Co., Dubuque, IA

Jung, R. E. and C. H. Jagoe. 1995. Effects of low pH and aluminum on body size, swimming performance, and susceptibility to predation of green tree frog (*Hyla cinerea*) tadpoles. Can. J. Zool. 73 : 2171–2183.

Kutka, F. J. 1994. Low pH effects on swimming activity of *Ambystoma* salamander larvae. Environ. Toxicol. Chem. 13 : 1821–1824.

Mordue, A. J. and A. Blackwell. 1993. Azadirachtin : an update. J. Insect Physiol. 39 : 903–924.

Power, T., K. L. Clark, A. Harnfenist, and D. B. Peakall. 1989. A review and evaluation of the amphibian toxicological literature. Can. Wildl. Serv. 61 : 1–122.

Punzo, F. 1992. Socially facilitated behavior in tadpoles of *Rana catesbeiana* and *Rana heckscheri* (Anura : Ranidae). J. Herpetol. 26 : 219–222.

——— 1993a. Ovarian effects of a sublethal concentration of mercuric chloride in the river frog, *Rana heckscheri* (Anura : Ranidae). Bull. Environ. Contam. Toxicol. 50 : 385–391.

——— 1993b. Effect of mercuric chloride on fertilization and larval development in the river frog, *Rana heckscheri* (Wright) (Anura : Ranidae). Bull. Environ. Contam. Toxicol. 51: 575–581.

——— 1995. An analysis of feeding in the oak toad, *Bufo quercicus* (Holbrook) (Anura : Bufonidae). Fla. Scient. 58 : 16–21.

——— 1997. Effects of azadirachtin on mortality, growth and immunological function in the wolf spider, *Schizocosa episina* (Araneae : Lycosidae). Bull. Environ. Contam. Toxicol. (in press).

Riechert, S. E., and T. Lockley. 1984. Spiders as biological control agents. Annu. Rev. Entomol. 29 : 299–320.

Schmutterer, H. 1985. Which insect species can be controlled by application of neem seed kernel extracts under field conditions ? Z. Angew. Entomol. 100 : 468–477.

——— 1990. Properties and potential of natural pesticides from the neem tree, *Azadirachta indica* . Annu. Rev. Entomol. 35 : 271–295.

Sokal, R. R., and B. J. Rohlf. 1981. Biometry. Second ed. W.H. Freeman Co., New York, NY

Sundram, K. M. S., and J. Curry. 1993. High performance liquid chromatographic determination of azadirachtin in conifer and deciduous foliage, forest soils, leaf litter and stream water. J. Liquid Chromat. 16 : 3275–3290.

Wan, M. T., R. G. Watts, and D. J. Moul. 1988. Evaluation of the acute toxicity to juvenile Pacific salmonids of hexazinone and its formulated products. Bull. Environ. Contam. Toxicol. 41 : 609–616.

———, R. G. Watts, and R. Strub. 1996. Evaluation of the acute toxicity to juvenile Pacific salmon of azadirachtin, neem extract and neem-based products. Bull. Environ. Contam. Toxicol. 56 : 432–439.

Waladde, S. M. 1989. Taste sensilla responses to liminoids, natural insect antifeedants. Insect Sci. Applic. 10 : 301–308.

Warkentin, K. M. 1992. Microhabitat use and feeding rate variation in green frog tadpoles (*Rana clamitans*). Copeia 1992 : 731–740.

Florida Scient. 60(3): 158–165. 1997
Accepted: November 6, 1996.

LITERATURE SEARCH FOR AIR QUALITY STUDIES CONDUCTED IN JACKSONVILLE, FLORIDA, 1945–1995

R. Del Delumyea, Tonya McKay, and Jennifer Horowitz

Millar Wilson Laboratory for Chemical Research, Jacksonville University,
Jacksonville, Florida

Abstract: *Records from government agencies, local industries, consultants and individuals who had conducted air quality research in Duval County over the past 30 years were searched to find all documentable papers. The literature search is described in this first of a three-part series which was part of an attempt to find the cause for the high lung cancer rate in Duval County (50% higher than the national average among white males).*

As evidenced by press reports, it is widely believed that the quality of Jacksonville's air is somehow responsible for the higher lung cancer rate. Jacksonville certainly has had problems with air quality. This dates as far back as the late 1940s, when women's nylon stockings deteriorated due to exposure to downtown air, which occurred again in the 1950s and 1960s (Harding et al., 1961; Sheehy et al., 1963). Interest in air quality continues today concerning odor emissions from two chemical plants, a large metropolitan sewage plant, plastics factory, brewery, coffee plant, fragrance manufacturer and a paint company in addition to two paper mills. Unfortunately, there was no single source for information on air quality over the period from 1950 to the present. Several organizations had responsibility for monitoring air quality over that time; however, no central repository for such information existed. It was therefore difficult to place current events in an historical perspective. To address this need, the present study was conducted.

Methods—The principal product of this project was a final report reviewing the documents and placing them in an historical perspective. Additionally, copies were obtained of 66 documents on air studies in Duval County/Jacksonville over the period from 1961 through 1991. A copy of that report is on file in the Medical Library at St. Vincent's Medical Center, along with all papers in the references. Details of access are provided at the end of this paper. A total of 66 documents were located; 46 had no quantitative data and were saved but were not useful for the work. One copy of each report was provided to the Lung Cancer Task Force of the Heart and Lung Institute at St. Vincent's Medical Center, 1800 Barrs Street, Jacksonville, FL. Information on access to the documents is provided at the end of this paper.

Persons contacted—The project would not have been successful if not for the assistance of several people and organizations who conducted the actual work in the (1950s and 1960s)

TABLE 1. List of agencies contacted.

1. The University of Florida, Environmental Engineering Department.
2. Florida State University, Department of Oceanography.
3. Environmental Science & Engineering, Inc.
4. Jacksonville Electric Authority.
5. Bio-Environmental Services Division.
6. State of Florida—Department of Environmental Regulation Tallahassee office, Jacksonville office.
7. Environmental Protection Agency—Region IV; Athens office, Atlanta office.
8. Scholte Consulting.
9. Regional Environmental Services Division.
10. Public Health Service.
11. Jacksonville Department of Transportation.
12. Public Health Service—Retired workers.
13. Jacksonville Health Planning Council.
14. KBN Engineering, Inc.
15. Florida State Board of Health.
16. The Florida Times-Union.
17. Jacksonville Public Library.
18. American Lung Association of Northeast Florida.

pre-E.P. A. days. Unfortunately they are not all available after 30–40 years. Mr. Charles Harding (Harding et al., 1961, 1966, 1967; Sheehy et al., 1963; Anonymous, 1964, 1965) died in a mysterious plane crash in the late 1960s. Harding worked with Bio-Environmental Services Division of the City of Jacksonville. This organization was the source for many of the articles found(Anonymous, 1965a, 1965b, 1970; Harding et al., 1966,1967; Environmental Science and Engineering, 1979(a–f); Kappelman and Dyer, 1978; Tutt, 1987, 1989, 1991; Barzyk et al., 1987; Mehta and Manning, 1988; Jacksonville Environmental Protection Board, 1990). Discussions with older workers provided leads to private sources (consultants, etc.), many of whom had additional reports.

Agencies contacted—A significant portion of the work for this project was locating and/or tracing documents. This was accomplished by several means. Initially, various agencies were contacted requesting any information readily available. Table 1 lists most of the agencies contacted during the study which were able to assist. To minimize interference with normal operations, names of the persons contacted have been omitted. It should be noted that Federal, State, and City/County agencies; individuals and consulting firms; college professors and researchers were approached. Some were able to provide original documents or duplicate copies; others loaned documents for photocopying; still others were able to suggest persons/agencies where additional documents might be located.

Newspaper search—The subject index of the Florida Times-Union, Jacksonville's major newspaper, was manually searched for the years of 1950 through 1992 (available at the Downtown branch of the Jacksonville Public Library). The index contains titles of articles; the articles were found (on microfilm) and read. They were then either abstracted or copied. Additionally, an "InfoTrak" literature search was conducted at the Jacksonville Public Library of newspaper articles or magazine stories on air quality in Jacksonville. None contained new or original data; however, the articles were useful in that they discuss popular thoughts on the topic of air quality at the time. The Florida Times-Union articles provided useful information that lead to finding documents, researchers, or organizations that were doing studies. The most significant was the mention of air pollution research done at the University of Florida in 1953. The University was contacted for additional information. Unfortunately, no documentation from that period of research was obtained. Most of the people that did the actual research are no longer able to be reached (many are deceased).

Library search—The majority of this work was conducted using the State University System of Florida, which includes the University of North Florida, Jacksonville; the University of Florida, Gainesville; and The Florida State University, Tallahassee. These libraries each have the Library User Information Service (LUIS), which permits on-line computer searching of books and documents on file throughout the University Library System. Each of these University libraries is connected through a computer link and documents at each can be ordered through the Inter-Library Loan (I.L.L.) service. Additional documents were obtained through I.L.L. using the libraries at Jacksonville University and the University of Georgia.

Keyword searches—"Manual" keyword searches were conducted at the University of North Florida Library, of all data bases available. Table 2 shows the keywords searched alone and in combination. Similar keywords were used to search for theses and dissertations in the publication "Dissertation Abstracts." Although several documents were located, it was decided that computerized literature searches of technical and medical journals would be significantly less time-consuming.

The computer literature search of several databases was performed by the Library Staff at the University of North Florida, using "DIALOG". This program searches a variety of databases, each of which covers a set period of time; none, however, dates back to the 1950's. The computer-generated summary of databases, keywords and positive responses ("hits"), is shown in Table 2. The services searched are listed in the Appendix. From the number of "hits", two things are immediately obvious: that such a search would be excessively time-consuming if not for the computer; and that the more selective the keyword string, the fewer number of documents fit the search criteria. Based on analysis of the keyword hits, abstracts were printed for potentially useful documents and, based on reading of the abstracts, approximately thirteen documents were ordered.

RESULTS—A total of 66 documents were located and copied. The complete list of these documents is presented (Literature Cited). The list provides a quick reference to studies conducted, the document title, year of the report, and the author(s) name. The information was generated from a LOTUS spreadsheet, sorted by date, and converted to a WordPerfect word processing file (which can be keyword searched).

Following preparation of the above table, it was concluded that an additional file was needed to facilitate the casual reader's understanding of the contents of a document, which may not be apparent from the title. A separate table of abstracts described the study, the data provided, pertinence to Jacksonville air quality measurement, etc. This file permits someone to read a brief summary of the document in order to decide whether it is of interest. As a word of caution, considerable bias is likely to have been introduced in deciding which portion of a particular report to mention. Reading the original document is recommended for completeness. The Medical Library at St. Vincent's Medical Center has a full set of documents. Examination of the papers, reports, etc. can be arranged by calling the Library at (904) 308-8165. Arrangements can be made for copying at a reasonable rate if requested.

TABLE 2. Results of the literature search.

Keyword list and code.	Total number of hits
1. Air()quality or air()pollution	300,480
2. Jacksonville or Duval()County or Northeast()Florida	810
3. 1 and 2 above	58
4. Sulfur()dioxide or ozone or hydrogen()sulfide or sulfuric()acid or particulate? or oxides or nitrous()oxide or carbon()monoxide or lead or hydrogen()fluoride	724,652
5. 2 and 4 above	27
6. 5 not 3	1

Source Start End	NTIS 1964–1992	MEDLINE 1966–	CHEM. ABST. 1967–	BIOSIS PREVIEW 1985–1992	POLLUT. ABST. 1970–	ENVIRO LINE 1970–	ENV. BIBLIO. 1974–	CONGRESS INFO. 1970–
Keyword				Hits				
1.	51,882	11,609	183,270	10,635	15,532	14,808	9,776	2,968
2.	379	67	67	43	34	28	7	185
3.	22	2	2	6	3	1	2	
4.	91,327	92,790	425,528	60,756	21,324	21,129	9,742	2,056
5.	14	3	2		2	1	2	1
6.	7	1	1	0	0	1	0	1
Printed	29	3	9	3	10	2	2	3

Acknowledgments—The Duval County Lung Cancer Study is funded through grants and donations from the American Lung Association, the Veterans of Foreign Wars Ladies Auxiliary, the Kirbo Charitable Trust, the Independent Life Insurance Company, the City of Jacksonville, and St. Vincent's Medical Center. This work was funded by a grant from the Duval County Lung Cancer Study (Task Force), the American Cancer Society, the American Lung Association, and the Environmental Protection Board of the City of Jacksonville.

LITERATURE CITED

Allen, E. R., C. H. Liao, P. T. Karney, and T. Brewer, 1985. Investigation of Odorous Emissions at a Jacksonville Wastewater Treatment Facility. Presented at: Annual Meeting, Florida Section, Air Pollution Control Association, September 29–October 1, 1985.

———, H. U. Hartenstein, and Y. Yang. 1987. Final Project Report—Review and Assessment of the Design and Operation of a Compost Biofiltration System for Odor Control. Submitted by: Environmental Engineering Sciences Department, University of Florida, Gainesville, FL 32611. Submitted to: Wastewater Branch, Water Services Division, City of Jacksonville, Department of Public Works, 2221 Buckman Street, Jacksonville, FL 32206. February, 1987.

——— , Y. Yang, and H. U. Hartenstein. 1987. Final Project Report—Odor Producing Agents, Their Sources and Control, Phase II. Submitted by: Environmental Engineering Sciences Department, University of Florida, Gainesville, FL 32611. Submitted to: Water Services Division, Department of Public Works, City of Jacksonville, Jacksonville, FL 32206. August, 1987.

Anonymous. 1965. Greater Jacksonville Air Pollution Control Program—Quarterly Progress Report. October 1 1964–December 31, 1964. Air Pollution Research Laboratory, Engineering and Industrial Experiment Station, University of Florida, Gainesville, FL. January 31, 1965.

———. 1965. Greater Jacksonville Air Pollution Control Program. Second Progress Report. Prepared by: Air Pollution Research Laboratory, Engineering and Industrial Experiment Station, University of Florida, Gainesville, FL.

———. 1971. Toward Environmental Health Quality for Jacksonville, FL. Prepared by: Environmental Health Study Committee of Jacksonville. Submitted to: Health Planning Council of the Jacksonville Area, Inc., Post Office Box 629, Jacksonville, FL 32202. Report supported by: U.S. Public Health Service Grant Number 04-P-0000003-03-0. November, 1971.

———. 1975. Jacksonville, Florida—Five Year Environmental Status Report. Prepared by: City of Jacksonville, Department of Health, Welfare and Bio- Environmental Services Division, 515 W. 6th Street, Jacksonville FL, 32266. February, 1975.

Barzyk, T., A. Luther, and J. Woosley. 1987. Assessment of Stage I Vapor Control Technology Application in Duval County. Presented, 1987 Annual Conference, Florida Section, Air Pollution Control Association, September 29, 1987.

Blot, W. J., J. E. Davies, L. M. Brown, C. W. Nordwall, E. Buiatti, A. Ng, and J. F. Fraumeni. 1982. Occupation and the High Risk of Lung Cancer in Northeast FL. Cancer 50: 364–371.

Buff, D. A. 1974. Verification of a Carbon Monoxide Diffusion Model for Jacksonville, FL. Masters Thesis, Department of Engineering, Univ. of Florida, Gainesville, FL.

Butcher, J. T. and R. D. Delumyea. 1991. Impact of toll removal on air particulate concentration in Jacksonville, Florida. J. Air and Waste Manage. Assoc. 41: 1601–1604.

——— and ———. 1992. Effect of Inorganic Components on the Determination of Elemental Carbon in Air Particulate Samples by Reflectance. Florida Scient. 55: 193–198.

Diamond, J. 1990. Life in Jacksonville—Quality Indicators for Progress. Prepared by: Jacksonville Community Council, Inc. Prepared for: The Jacksonville Chamber of Commerce, November, 1988.

EMERY, L. H. 1967. Investigation of Particulate Concentration in a Polluted Atmosphere Below 500 Feet. Masters Thesis, Department of Engineering, Univ. of Florida, Gainesville, FL.

ENVIRONMENTAL SCIENCE AND ENGINEERING, INC. 1979a. Citizen Complaint Summary, Odor Abatement Study. Prepared for: City of Jacksonville, Department of Health, Welfare and Bio- Environmental Services Division, Jacksonville FL. Submitted by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-001. November, 1979.

———. 1979b. Summarization of Citizen Questionnaire Results, Odor Abatement Study. Jacksonville, FL. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL and PLANTEK CORP. Jacksonville, FL ESE Document #: 78-147. March, 1979.

———. 1979c. Analytical Results Characterizing the Twenty- Four Hour Variation of Volatile Organics at Site 3-Odor Abatement Study. Prepared for: City of Jacksonville, Bio- Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003. September 28, 1979.

———. 1979d. Analytical Results Characterizing Volatile Organics in the Ambient Air Near Suspected Odor Sources-Odor Abatement Study. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003. November, 1979.

———. 1979e. Odor and Toxicity Ratings of Airborne Volatile Organic Compounds-Odor Abatement Study. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003. November 28, 1979.

———. 1979f. Sampling and Analysis of Volatile Organic Compounds for the Odor Abatement Study, Jacksonville, FL. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Submitted by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003. November, 1979.

———. 1979g. Effects of Meteorology on Odors-Odor. Abatement Study. Prepared for: City of Jacksonville, Bio- Environmental Services Division, Jacksonville, FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003 November, 1979.

———. 1979h. Review of Industrial Odor Control Methods, Odor Abatement Study-OAS. Prepared for: City of Jacksonville, Department of Health Welfare and Bio-Environmental Services Division, Jacksonville, FL. Submitted by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-004. November, 1979.

———. 1980. Project Summary Report—Odor Abatement Study. Prepared for: City of Jacksonville, Department of Health, Welfare, and Bio-Environmental Services Division. Submitted by: Environmental Science and Engineering, Inc. Gainesville, FL Document Number 78-147-001. January, 1980.

ERFANI-EZATI, G. 1984. Measuring the Benefits From Air Pollution Abatement on Human Health and Welfare: A Case Study of Jacksonville, FL. Ph. D. Dissertation, Department of Economics, The Florida State Univ., Tallahassee, FL. August 1984.

———, AND F. W. BELL. 1988. The impact of migration on air quality dose-response functions. Air Pollut. Control Assoc. J. 38: 485.

FAYSON, N., 1986. Toll Collection-Matthews Bridge; A Consultative Health Survey. DOT Reference # J86-8002 HP. April 10, 1986.

FISHER, R. 1976. Air Quality Modeling in Jacksonville, Florida, Volume I. Prepared by: PEDCo-Environmental Specialists, Inc. Suite 13, Atkinson Square, Cincinnati, OH 45246. Prepared for: U.S. Environmental Protection Agency, Region IV, Atlanta, GA and Florida Department of Environmental Regulation, Tallahassee, FL 32301. May, 1976.

GRENIER ENVIRONMENTAL SCIENCES, INC. 1974a. Development of Regional Impact Application for Development Approval and Complex Source Permit for the Bay Meadows Shopping Mall Jacksonville—Duval County, Florida. Prepared by: Grenier Environmental Sciences, Inc. Prepared for: Edward J. DeBartolo Corp. June, 1974.

———. 1974b. Seven Day Carbon Monoxide Monitoring Results and Findings Required as Part of Complex Source Permit Application for The Baymeadows Shopping Mall Jacksonville- Duval County, Florida. Prepared by: Grenier Environmental Sciences, Inc. Prepared for: Edward J. De Bartolo Corp, July, 1974.

Harding, C. I., S. B. McKee, and J. J. Schueneman. 1961. A Report on Florida's Air Resources. Prepared by: Bureau of Sanitary Engineering, Florida State Board of Health. Submitted to: Florida State Board of Health, Jacksonville, Florida. February, 1961.

———, A. L. Danis, and J. B. Koogler. 1966. Greater Jacksonville Air Pollution Control Program. Final Progress Report. Bioenvironmental Engineering Dept, College of Engineering, Univ.of Florida, Gainesville, FL. August, 1966.

———, A. L. Danis, J. B. Koogler, D. A. Falgout, T. R. Kelley, and R. S. Sholtes. 1967. Clearing the Air in Jacksonville. Performed by Air Pollution Research Laboratory, Bioenvironmental Engineering Department, Univ. of Florida, Gainesville, FL. Published by: Air Improvement Committee of Greater Jacksonville, Inc. October, 1967.

Hennekens, C. H., J. E. Davies, R. S. Levine, F. W. Briese, and C. W. Nordwall. 1981. Trends of lung cancer in Northern Florida. South. Med. J. 74: 566–568.

Horm, J. W., A. J. Amire, and J. L. Young, Jr. 1984. Seer Program: Cancer Incidence and Mortality in the United States, 1973–81. Bethesda, Md. U. S. Dept. of Health and Human Services. Publication No. NIH 85-1837.

Immerman, F. W. and J. L. Schaum. 1990. EPA—Nonoccupational Pesticide Exposure Study (NOPES). EPA/600/S3-90/003. Feb. 1990.

Jacksonville Community Council, Inc. 1988. Life in Jacksonville—Quality Indicators for Progress. Prepared for: The Jacksonville Chamber of Commerce. Prepared by: Jacksonville Community Council, Inc. November, 1988.

Jacksonville Electric Authority. 1982. Environmental Impact Statement—JEA St. Johns River Power. EPA 904/9-82-086. June 1982.

Jacksonville Environmental Protection Board. 1989 (and subsequent years). Annual Report. City of Jacksonville, 421 W. Church St., Jacksonville, FL 32202.

———. 1990. Annual Report. City of Jacksonville, 421 W. Church St., Jacksonville, FL 32202.

Kappelman, R. L. and R. T. Dyer. 1978. Utilization of Power Production and Air Quality Models to Develop a Cost Effective Sulfur Dioxide Emissions Regulation. Jacksonville, FL—A Case Study. Presented, 71st Annual Meeting of the Air Pollution Control Assoc., Houston, Texas, June 25–30, 1978.

——— and N. B. Gianaza. 1988. Resolving Modeled Ambient Sulfur Dioxide Exceedances—A Case Study. Source not found.

——— and I. M. Koger. 1970. Pollution Control in Jacksonville. Prepared by: Health Planning Council of the Jacksonville Area, Inc., P. O. Box 629, Jacksonville FL 32202. Report supported by U. S. Public Health Service, Grant Number 04-P-000003-02-1. September, 1970.

Mehta, K. K., W. E. Tutt, D. Swartz, L. Hunter, and Besd Personnel. 1985. The Initial Strategies and Development of the Air Toxics Program for the City of Jacksonville, FL.

———, W. E. Tutt, R. Baskin, D. Swartz, and L. Hunter. 1985. A Comparative Study of Select Organic Sulfur Compounds in the Wastewater at Two Organic Chemical Companies and at The Buckman Street Sewage Plant. Presented: 1985 Annual Conf., Florida Air Pollution Control Association, St. Augustine, FL. September 29–October 1, 1985

——— and J. L. Manning. 1988. Hatching an Environmental Battle Plan in Jacksonville.

Mullins, B. M. 1978. Geochemical Aspects of Atmospherically Transported Trace Metals Over the Georgia Bight. Masters Thesis, Dept.of Geophysical Engineering, Georgia Institute of Technology, Atlanta, GA. May, 1978.

Pedco Environmental Specialists, Inc. 1975. Particulate and Sulfur Dioxide Area Source Emission Inventory for Duval, Hillsborough, Pinellas and Polk Counties, Florida, Volume I Prepared by: PEDCo-Environmental Specialists, Inc. Suite 13, Atkinson Square, Cincinnati, OH 45246. Contract No. 68-02-1375, Task Order No. 95PN 3155-I. Prepared for: U.S. Environmental Protection Agency, Region IV, Air Programs Branch, Atlanta, GA 30309. November, 1976.

PFETZING, E. 1976. Air Quality Modeling in Jacksonville, FL. Volume I. Prepared by: PEDCo-Environmental Specialists, Inc. Suite 13, Atkinson Square, Cincinnati, OH 45246. Contract No. 68-02-1375, Task Order No. 24. Prepared for: U.S. Environmental Protection Agency, Region IV, Air Programs Branch, Atlanta, GA 30309, and Florida Dept. of Environmental Regulation, Tallahassee, FL 32301. November, 1976.

RESEARCH DEPARTMENT, JACKSONVILLE AREA CHAMBER OF COMMERCE. 1970. Pollution Abatement Efforts by Industries in Jacksonville. Research Department, Jacksonville Area Chamber of Commerce, 604 Hogan Street, Jacksonville, FL 32202. October, 1970.

ROSS, A. M. 1974. Toward Environmental Health Quality For Jacksonville, Florida: Volume II. Prepared for: Jacksonville Health Planning Council. December, 1974.

SHEEHY, J. P., J. J. HENDERSON, AND C. I. HARDING. 1963 A Pilot Study of Air Pollution in Jacksonville, FL. U.S. Department of Health, Education, and Welfare, Public Health Service, Division of Air Pollution, Cincinnati 26. OH, April, 1963.

———, ———, ———, AND A. L. DANIS. 1962. A Pilot Study of Air Pollution in Jacksonville, FL. U.S. Dept. of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, OH. December, 1962.

SHELLHORN, J. 1987. Report on CO Special Studies Fuller Warren and Matthews Bridge Toll Areas Jacksonville, FL. Prepared by: Florida Dept. of Environmental Regulation. Prepared for: Mr. Don Stuart, Mobile Source Program, Dept. of Environmental Regulation, Tallahassee, FL .

SMALLWOOD, S. 1987. Ambient Air Monitoring Report. Prepared by: Florida Dept. of Environmental Regulation, Division of Air Resources Management.

STEARNS-ROGER, INC. 1975. Ground Level Sulfur Dioxide Concentration Estimates Using the Air Quality Display Model. Prepared for: Jacksonville Electric Authority, Project C-15972. Prepared by: Environmental Sciences Div., Stearns- Rogers, Inc. January, 1975.

TUTT, W. E. 1987. Unique Odor Problems and Proposed Solutions in Jacksonville, FL. Presented, 80th Annual Meeting of the Air Pollution Control Assoc., New York, NY, June 21–26, 1987.

———. 1989. Setting an Ambient Odor Standard. Presented, 82nd Annual Meeting and Exhibition. Anaheim, California, June 25–30, 1989.

———. 1991a. Successful Application of Odor Control Technology at a Polyester Resin Manufacturing Facility. Presented at the 84th Annual Meeting and Exhibition, Vancouver, British Columbia. June 16–21, 1991.

———. 1991b. A Regulatory Approach for Controlling Odors in The Terpene Chemical Manufacturing Industry.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, OFFICE OF AIR QUALITY PLANNING AND STATISTICS. 1992. National Air Quality and Emission Trends Report, 1991. Doc.No. 450-R-92-001, 1992.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. 1986. National Primary and Secondary Ambient Air Quality Standards. Sect. 50.4, 50.5 (sulfur dioxide); Sect. 50.6 (particulate matter); Sect. 50.8 (carbon monoxide); Sect. 50.9 (ozone); Sect. 50.11 (nitrogen dioxide); Sect. 50.12 (lead). Code of Federal Regulations, Part 50.222.

VERNIER, L. AND R. BALD. 1971. Toward Environmental Health Quality for Jacksonville, FL. Prepared by: Mrs. Anne M Ross, Chairman, Environmental Health Planning Committee of Jacksonville. Prepared for: Health Planning Council of the Jacksonville Area, Inc.

WILLIAMS, D. T. 1970. Portable Spectrometric Analyzer For Air Pollutants. Prepared for: Public Health Service. PB-230-162. December 22, 1970. Distributed by: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151.

WILSON, A. L. 1971. An Atmospheric Diffusion Model for Jacksonville, FL. Masters Thesis, Dept. of Engineering, Univ. of Florida, Gainesville, FL.

WINCHESTER, J. W. 1981. Air Pollution Sulfuric Acid Reactivity and Lung Cancer Risk in

Florida (Final Research Grant Report to The American Lung Association of Florida with a Summary of Findings from Prior Year Grant), The Florida State Univ., Tallahassee, FL.

———. 1987. Air Quality and Epidemiology of Lung Cancer in Florida). (Draft of a Report Never Submitted.) Prepared at The Florida State University, Talahassee, FL. March, 1987.

———. 1989. Regional anomalies in chronic obstructive pulmonary disease; comparison with acid air pollution particulate characteristics. Arch. Environ. Toxicol. 18: 291- 306.

——— AND A. C. D. LESLIE. 1978. Florida Sulfur Oxides Study—Florida Sulfur Aerosol Characterization. Prepared for: Florida Environmental Regulation Commission. Document # TD0885.5.S85 Seg 1. Prepared for: Florida Environmental Regulation Commission. Prepared by: Department of Oceanography, Florida State University. January, 1978.

———, F. W. LEYSIEFFER, AND Y. C. PARK. 1981. Geographic Distributions of Lung Cancer Mortality and Estimated Sulfuric Acid Aerosol Concentration in Southeastern U. S. Atlantic Coastal Counties. Technical Report, July, 1981.

———, S. FAN, AND S. LI. 1984. Detection of Strong Acidity in Aerosols of North Florida. Interim Report to the American Lung Association of Florida. November 26, 1984.

YANG, Y. 1988. Odor Emission and Its Control in a Wastewater Treatment Plant with Industrial Sources. Masters Thesis, Dept.of Engineering, Univ. of Florida, Gainesville, FL.

ZAEBST, D. D. 1989. In Depth Survey Report of P-I-E Nationwide, Inc. PB90-130055, Department of Commerce. April, 1988.

Florida Scient. 60(3): 166–174. 1997
Accepted: December 6, 1997.

APPENDIX

Addresses of Search Services

NTIS, National Technical Information Service, U. S. Department of Commerce, Technology Administration, Springfield, VA 22161. (703) 487-4650

MEDLINE, (on-line network of the National Library of Medicine, 8600 Rockville Pike, Bethesda, MD 20894. (301)496-6308. Internet: publicinfo@occshost.nlm.nih.gov

CHEM. ABST., Chemical Abstracts Service (subsidiary of American Chemical Society), 2540 Olentangy River Rd., Box 3012, Columbus, OH 43210-0012. 614)447-3600.

BIOSYS PREVIEW, BIOSIS, 2100 Arch Street, Philadelphia, PA. 19103-1399. (800) 523-4806.

POLLUT. ABST., Pollution Abstracts. Cambridge Scientific Abstracts, 7200 Wisconsin Ave.-Sixth Floor, Bethesda, MD. 20814. 301) 961-6750.

ENVIROLINE, Environment Abstracts, Congressional Information Service, Inc. 4520 East-West Highway, Suite 800., Bethesda, MD. 20814-3389. (800) 638-8380. (301) 654-1550.

ENV. BIBLIO., Environmental Studies Institute, 800 Garden Street, Suite D, Santa Barbara,, CA 93103. (805)965-5010.

CONGRESS INFO. Congressional Information Services, 4520 East-West Highway, Bethesda, MD 20814. (800) 638-8380.

TRENDS IN AIR QUALITY RESEARCH IN NORTHEAST FLORIDA, 1945–1995 AND COMPARISON OF AIR QUALITY IN JACKSONVILLE, FL WITH NINE OTHER CITIES IN THE UNITED STATES, 1972–1992

R. Del Delumyea, Tonya McKay, and Jennifer Horowitz

Millar Wilson Laboratory for Chemical Research, Jacksonville University,
Jacksonville, FL 32211

Abstract: *This second paper follows one on the first stage (Delumyea et al.,1997) of a search for the source of the anomalously high rate of lung cancer in Duval County, Florida, the subject of 66 studies conducted over a thirty year period are reviewed. It is shown that interest in air quality issues has always been high but has varied over the study period. Concentrations of the six "criteria pollutants" requiring monitoring by the U. S. Environmental Protection Agency since 1976 in Jacksonville are compared with those of nine other comparably- sized cities in the United States-two on the east coast, two on the west coast and five in the "heartland". It is shown that Jacksonville is actually among the cleanest cities, at least as regards the six criteria pollutants.*

Concern over air quality in Jacksonville dates as far back as the late 1940s, when women's nylon stockings deteriorated due to exposure to downtown air (Harding et al., 1961; Sheehy et al., 1963). A study of deterioration of nylons worn by workers downtown suggested the damage was caused by sulfuric acid from an old World War II surplus floating power station in use around that time. In 1964, a similar episode of nylon stocking "disintegration" among court house workers was studied (Anonymous, 1965). Sulfuric acid aerosols were again suggested as the offending compound. Air pollution in general became a problem in and since the 1950s; the most prevalent symptom has been an odor that has become distinctive to Jacksonville. The smell was even referred to by the host of the popular television game show, Jeopardy, a few years ago. Citizens' groups began complaining about bad odor in 1958. The paper industry was the biggest culprit of odorous air pollution in the 1950s. Interest in air quality continues today concerning odor emissions from two chemical plants, a large metropolitan sewage plant, brewery, coffee plant, fragrance manufacturer, a paint company and two paper mills.

The chronologically first paper found was a 1961 study by the Florida State Board of Health titled "A Report on Florida's Air Resources" (Harding et al., 1961. The governor of the State of Florida, LeRoy Collins, requested the State Health Officer (Dr. Wilson Sowder)" . . . undertake a survey of Florida's air resources and recommend steps Florida should take to avoid development of further air pollution problems''. Two pages of recommendations at the state, county and city level were given. The air in the state was discussed in four quadrants (northwest, northeast, southern and central). In Northeastern Florida, the odorous emissions from two paper mills, two superphosphate plants in Jacksonville (which emitted dust and ''corrosive gases''), volatile organic emissions from an oil recycling plant and large petroleum tank farms, and a terpene products plant (releasing sulfurous and aromatic emissions) were listed as contributors to lowered air quality in the region. In another early paper, ''A Pilot Study of Air Pollution in Jacksonville, Florida'', (Sheehy et al., 1963) conducted by the U. S. Public Health Service, U. S. Department of Health, Education and Welfare, problems which existed at the time (December, 1962) were evaluated. Fluorides, sulfur dioxide, hydrogen sulfide, nitrogen dioxide, oxidants, and particulates were identified as study-compounds. The presence of two fertilizer plants on the west side of the St. Johns River was indicated as the source of fluoride on the east (Arlington) side of the river. ''Airborne fluoride concentrations capable of causing damage to sensitive plants under proper growth conditions were found during this study.'', the report (Sheehy et al., 1963) concluded. Darkening of paints in the Arlington area indicated the presence of hydrogen sulfide, a noxious compound and one present in Jacksonville's air for the following three decades. In the former study, oxidant concentrations in Jacksonville were compared to bad air days in Los Angeles, and it was concluded that Jacksonville's air ''wasn't that bad''; however, the final statement of the report summary was: ''It is concluded from this study that the city of Jacksonville has air pollution problems.''

The 1960s saw an increase in organizations that dealt with situations like air pollution complaints. The Bio-Environmental Services Division of the City of Jacksonville hired the Engineering and Industrial Experiment Station of the College of Engineering at the University of Florida, in Gainesville, to conduct a study of the ''Greater Jacksonville Air Pollution Control Program'' (Harding, et al., 1966). The funds for the study came from the Jacksonville City Commission, Duval County Commission and the Air Improvement Committee of Greater Jacksonville, Inc. The Florida State Board of Health got involved with investigation of air resources in the state in 1961, including Jacksonville (Harding et al., 1961). Other participants in that study included the Bureau of Sanitary Engineering of the Florida State Board of Health, Technical Assistance Branch, Division of Air Pollution and Public Health Service, U. S. Department of Health, Education and Welfare. The Jacksonville Area Chamber of Commerce supported an air clean-up study with a donation of $150,000. Much of the research that was done was in generic air pollution work with no focus on a particular pollutant. Phosphate mining and phosphate dust also were identified as problems in the 1960s. The State Board of Health got involved with legislation. The issue of sulfur dioxide emissions from utility plants also came to the forefront of air pollution problems about the same time.

A major study was conducted in 1966 called "Clearing the Air in Jacksonville" (Harding et al., 1966). A television special of the same name was released in the same year (1966); however, the last copy of the tape of the television show was lost and cannot be located. According to the Florida Times-Union, 1969 was seen as the year that Floridians took on the battle against pollution. A survey was conducted in 1970, 1971, and 1974 by the Health Planning Council of the Jacksonville Area, Inc. of pollution control efforts in the area (Anonymous, 1970; Wilson, 1971).

1970 was the beginning of an environmental movement that grew both nationally and locally, particularly from citizen involvement during the 1960s. The Research Department of the Jacksonville Area Chamber of Commerce published a 135 page report of "Pollution Abatement Efforts by Industries in Jacksonville (Environmental Science and Engineering, 1979a; Anonymous, 1970). Water, solid waste, and particularly air quality issues were addressed. The national trend and alarm about air quality deterioration was noted in the introduction. As has been typical of the efforts in Northeastern Florida, industry cooperation in Duval County has been excellent over the past three decades. Ninety-seven firms returned useful information on the efforts their organizations were taking to reduce pollution in the area. Nationally, the Environmental Protection Agency spurred the clean-up of air, land, and water across the country. Large developments were required to submit "Development of Regional Impacts" statements (Grenier 1974a, 1974b). Environmental Impact Statements were required for major construction projects. In Jacksonville, the focus was on odor (Environmental Science and Engineering, 1979a–f, 1980; Mehta et al., 1985b; Winchester, 1987, 1989; Allen et al., 1985; Barzyk et al., 1987; Zaebst, 1989; Tutt, 1991a,b; and Butcher and Delumyea, 1991). Odor became a big problem in the 1980s (Hennekens et al., 1981), with citizen complaints being the biggest reason for local government's growing interest (Environmental Science and Engineering, 1979b,c). The issue of sulfur dioxide emissions from local industry and utility plants had been an on-going concern since the 1960s (PEDCo, 1975; Pfetzing, 1976; Mullins, 1978; Environmental Science and Engineering, 1979a; Jacksonville Community Council, Inc., 1988). Carbon monoxide levels were researched around and on the bridges throughout the city (Fayson, 1986; Shellhorn, 1987). Point sources of odor, such as paper mills and the City's sewer treatment plant (Mehta et al., 1985, among othrs) were studied.

Only a few reports from the 1990s are included in the present study. It is hard to determine what the upcoming trends will be; however, continued reductions in sulfur dioxide and an increasing focus on air toxics levels are expected as a result of the Clean Air Act Amendments of 1991. Continued efforts to maintain lower ozone levels will be required. Throughout the period from 1960–1990, studies indicated the high rate of respiratory problems, particularly chronic obstructive pulmonary disease (COPD) (Tutt, 1989, Winchester, 1989) and lung cancer (Wolfe, 1994; Jacksonville Electric

Authority, 1982; Winchester, 1987; Blot et al., 1982; Erfani-Ezati, 1984; Tutt, 1989). While not the focus of the present study, a more thorough file is available at the Medical Library at St. Vincent's Medical Center, which has a full set of the disk and documents. Examination of the papers, reports, etc. can be arranged by calling the Library at (904) 308-8165. Arrangements can be made for copying at a reasonable rate if requested. Some of these reports are included in the current list since they were conducted in Jacksonville/Duval County/Northeast Florida.

SEARCH FOR KNOWN CARCINOGENS IN JACKSONVILLE AIR FROM REPORTED DATA—*Organic compounds*—Tables 1 and 2 present a summary of compounds identified or selected for study in reports found in the review of the historical record of air quality in Jacksonville, Florida (Delumyea et al., 1997). Listed in Table 1 are the total number of references, and years in which those studies were reported. This provides an indication of the importance of the compound from the number of references shown and the time scale over which the experiments were conducted. Sulfur dioxide, for example had twenty-two references, followed by particulate matter with twenty; both were studied from the period between 1961 and 1991. The compounds studied were not generally related to health issues though some references mention adverse health impacts of the studied compounds.

Since one emphasis of this work is the identity of known or suspected carcinogens (specifically lung), Table 2 was constructed from reports which contain gas chromatographic and mass spectrometric identification of compounds. A study was conducted in 1979 of the presence of volatile organic compounds (VOC's) in Jacksonville's air as part of an odor investigation (Environmental Science and Engineering, 1979d,e). The analytical methodology (Tenax trap, thermal desorption, GC/MS analysis) was described in a separate paper (Environmental Science and Engineering, 1979f). The site was located next to the Union-Camp Corporation, which may be responsible for the majority of the compounds identified. Classes of compounds identified were: aromatic compounds, sulfur-containing species, chlorofluorocarbons (Freons®), and miscellaneous other chlorinated compounds. Specific compounds are noted in Table 2. These compounds were detectable due to the low analytical sensitivities of the methods of analysis employed. Some detected compounds listed are known or suspected carcinogens; however, the concentrations are very small (reported in nanograms per cubic meter) and most are "typical" of urban air. Benzene, toluene and ethylbenzene (all known carcinogens and common constituents of gasoline vapor) are reported; however, this is probably due more to the sensitivity of the analytical method than the significance of their presence. Subsequent studies of the presence of such compounds which were identified contained no quantitative data. It was likely concluded that the concentrations were sufficiently low that their presence was not likely to be abnormal or account for any unusual health risks.

TABLE 1. List of analytes and document numbers from HRAQDC.

Pollutant	Number	Report Years (19XX)
Alkaline dust	1	89
Asbestos*	1	82
Aldehydes (N.O.S.#)	1	70
Carbon monoxide	15	63, 70, 70, 71, 74, 74, 74, 74, 74, 86, 86, 87, 88, 89, 90
Dimethyl sulfide	4	80, 87, 89, 91
Dimethyl disulfide	1	91
Fluorides	1	62, 63
Ethylene oxide	1	90
Hydrocarbons	9	61, 70, 70, 71, 74, 79, 79, 82, 88
Hydrochloric acid	1	84
Hydrogen sulfide	9	62, 63, 64, 65, 66, 79, 87, 89, 91
Lead	4	86, 87, 89, 90
Methyl mercaptan	2	87, 87
Nitric acid	1	84
Nitrogen dioxide	7	63, 74, 86, 87, 88, 89, 90
"Nitrogen oxides"	9	61, 64, 66, 67, 70, 71, 74, 74, 79
Organic compounds	1	79
Oxidants	3	62, 63, 70
Odors	1	71
Ozone	6	67, 85, 87, 88, 89, 90
Particulate matter* (includes Total Suspended Particulate Matter)	20	61, 63, 64, 65, 66, 67, 70, 70, 71, 71, 74, 75, 76, 81, 84, 85, 85, 87, 88, 89, 91
Particulate fluoride	1	61
Particulate sulfur	1	89
Particulate sulfate	1	85
Particulate nitrate	1	85
Polynuclear aromatics*	1	74
Pollen	1	71
Pesticides	1	90
Sulfate turpentine	1	91
Sulfide gases	1	67
Sulfur dioxide	22	61, 62, 63, 64, 66, 71, 74, 74, 75, 75, 76, 78, 84, 85, 87, 88, 88, 89, 89, 90, 91, 91
Sulfur oxides	5	70, 70, 71, 78, 75
Sulfuric acid	4	61, 81, 84, 87
Total reduced sulfur	6	85, 85, 87, 87, 88, 91
Terpenes#	1	80
Volatile org. compounds	5	63, 79, 79, 87, 90
Xylenes	2	79, 80

# N.O.S. = Not Otherwise Specified.
** Number in parentheses is relative toxicity on 1–10 scale.
* Known Carcinogen.

The issue of the toxicity of the compounds identified in the odor studies conducted in the late 1970s is summarized on page 16 of a document (Hennekens et al., 1981) titled "Project Summary Report Odor Abatement Study" in 1980. Compounds identified include benzene (a known carcinogen

TABLE 2. Identity of selected volatile organic compounds found in selected references.

Sheehy et al., 1963.	Env. Sci. and Eng. Inc., 1979.
aldehydes#	benzene* (1)
ketones#	toluene* (5)
	ethyl benzene* (5)
	xylenes* (5)
hydrocarbons	styrene* (3)
benzene*	methylene chloride (7)
trichlorofluoromethane	dimethyl sulfide (3)
trichloroethene	thiophene (2)
1,1,1-trichloromethane	methylthiophene (2)
tetrachloroethene	chloromethane (4)
carbon disulfide	acetaldehyde (5)
dimethyl sulfide	methyl ether (4)
dimethyl disulfide	dichlorodifluoromethane (10)
ethylmethyl sulfide	acetone (9)
thiophene	pentane isomer (8)
methylthiophene	hexane isomer (5)
terpenes (α, β pinene)	hexene isomer (4)
	1,1,2-trichloroethane (7)
	heptane isomer (7)
	octane isomer (8)
	α-pinene (6)
	β-pinene (6)
	benzaldehyde (3)
	bromodichloromethane (5)
	pentene isomer (5)
	terpene isomers (6)
	C_3 alkylbenzene (4)
	methyl vinyl ketone (4)
	methyl ethyl ketone (4)
	pentadiene isomers (5)
	nonane isomer (7)
	trichlorotrifluoroethane (9)
	thiophene isomer (3)
	1-methyl pyrole (4)
	octene isomer (6)
	fenchone (4)
	isobutane (2)

# N.O.S. = Not Otherwise Specified.
** Number in parentheses is relative toxicity on 1–10 scale.
* Known Carcinogen.

and common constituent of gasoline), carbon tetrachloride and trichloroethene, and the sulfur-containing compounds (which though odorous are not known carcinogens). The study correctly and rightfully points out that the levels detected were orders-of-magnitude below OSHA standard levels set for occupational exposure. The relative toxicity of the compounds identified on a one to ten scale, where (1) is worst, was developed. Those numbers are shown for each identified volatile organic compound detected.

It would be incorrect to say that there was anything "unusual" in their presence in typical urban air. In summary, nothing was identified in Jacksonville's air which could be responsible for an anomalous health risk.

Metals—A report in the journal *Scientific American* (Anonymous, 1993) reported on a study by the Harvard School of Public Health in which the health of over 8,000 residents in six American cities were studied for 14–16 years. The study found a " . . . 26% higher risk of premature death in the city with the most polluted with ambient particles as compared to the least polluted city surveyed". The significance of this observation was found in the fact that all cities studied had particulate concentrations below the Federal Guideline. The Federal government requires cities, including Jacksonville, to monitor air particulate concentrations as one of six "priority pollutants" which contribute to degraded air quality. These particles are 10 microns or smaller, the so-called "inhalable" particulates, and the device used to collect them is a "PM-10 monitor". The atmospheric PM-10 concentration is determined by drawing air at a measured rate through a preweighed glass or quartz fiber filter for a known period of time. The weight gain of the filter divided by the air volume results in the air concentration. The value, while indicative of air quality, is chemically non-specific.

Perhaps the most widely studied metal in particulate matter has been lead, which used to be emitted from automobile exhaust. In urban areas, the adverse effects of airborne lead in particulate matter has long been known and, since the banning of leaded gasoline, is now considered under control in the United States, with levels reaching background in most areas. Other metals in ambient air are usually present in trace quantities; however, four have been identified as carcinogens with a direct link to lung cancer: arsenic, nickel, chromium and beryllium.

The importance of particulate matter was recognized when the EPA required its monitoring as part of the six "Priority Pollutants". A recent newspaper article in the Sarasota Herald-Tribune presents the case that particulate concentration is related to adverse medical effects of "air pollution". In the past, the study of health effects of "air pollution" has concentrated on the gaseous components of the priority pollutants—notably sulfur dioxide and ozone. The effects of TSP (PM-10, defined above) have not been completely addressed, although sulfur levels of particulate matter in urban areas have been studied for over two decades by the Harvard School of Public Health. Various studies point to the acidity of fine particles and their possible effects on respiratory function, particularly in persons with respiratory disease. A series of studies conducted by Brigham Young University has placed new emphasis on the adverse effects of particulate matter, especially the smaller, inhalable-sized particles. The PM-10 values for two valleys in Utah were correlated with school absenteeism (Ransom and Pope, 1992), daily mortality (Pope et al., 1992), respiratory health (Pope et al., 1991), acute respiratory health (Pope and Dockery, 1992), respiratory hospital admissions (Pope, 1991); and general respiratory disease (Pope, 1989). The individual

TABLE 3. Average concentration of samples collected at seven locations in Jacksonville, expressed as arithmetic average concentration, μg/m³ (Mehta, et al., 1985).

	Date			
Metal	2/24&3/08/85	3/20&4/1/85	4/13&4/25/85	5/7&5/19/85
Beryllium	Not detected	Not detected	Not detected	Not detected
Magnesium	0.6574	0.311	0.5004	0.4506
Vanadium	0.0335	0.0623	0.020	0.00276
Chromium	0.005	0.0024	Not detected	Not detected
Iron	0.3616	0.3290	0.4188	0.4833
Cobalt	Not detected	Not detected	Not detected	Not detected
Nickel	0.00955	0.00386	0.00916	0.0060
Copper	0.1721	0.162	0.1186	0.1674
Zinc	0.079	0.071	0.0917	0.0471
Cadmium	0.00033	0.00023	0.0005	0.0003
Tin	0.0193	0.0135	0.0147	0.0177
Antimony	Not detected	Not detected	Not detected	Not detected
Lead	0.0528	0.0107	0.0453	0.1312
Arsenic	Not detected	Not detected	Not detected	Not detected
Manganese	0.00067	0.00011	0.0049	0.00060
Mercury	(Not determined)	—	—	—

parameters were found to have positive correlation with particulate concentration. Mitigating circumstances which may reduce the direct applicability of these studies to Jacksonville include the topography (the Great Salt Lake Basin and surrounding mountains trap pollution), the presence of a steel mill in one of the study valleys, different meteorological conditions in the two locations, and the higher PM-10 concentrations observed (up to three times greater than in Jacksonville).

More recently, attention has again focused on air particulates as a serious pollutant (Reichard, 1995). At present, no studies are being conducted in Jacksonville on these potential problems.

A study was conducted in preparation of the Clean Air Act amendments of sixteen metal species present in air particulate matter at seven sites in Jacksonville. Compounds not found were stated as ND (not detected). For comparative purposes, the average arithmetic concentration at the seven sites was calculated from reported data using zero for a non-detect concentration. These are summarized in Table 3. As stated in the report (Mehta, et al., 1985a), the numbers are, of themselves, not significant and serve as the only results of such analyses in the documents found. They are summarized in Table 3 in case someone else has values against which to compare these data. Of the four known lung carcinogens (arsenic, nickel, chromium and beryllium), arsenic and beryllium were not detected in Jacksonville air in the 1985 study. Concentrations of the remaining species (chromium and nickel) were reported in NANOgrams per cubic meter. Nickel ranged from 3 to 9 nanograms per cubic meter and chromium concentrations ranged around 2 ng/m³. These are considered low and background levels.

EPA Sample Results, 1979–1992—*General*—The Clean Air Act was passed in 1970, and the Environmental Protection Agency was formed to establish federal environmental policy and to act as the lead agency in assuring clean air for all citizens. Based on their potential for adverse environmental response, either to property (primary standard) or to health (secondary standard), six chemical species or classes were identified as "priority" or "criteria" pollutants: ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, lead, and total suspended particulate matter. Whereas the latter is mass-based, the others had maximum concentrations established. The State of Florida similarly established maximum limits beyond which cities were not to go. The city of Jacksonville, along with other larger cities in the U.S., is required to monitor air quality on a regular basis. Protocols for this monitoring have been established and are followed in the cities studied. The Table lists the criteria pollutants and the current Federal and Florida limits.

The *raw* data from these analyses were obtained from EPA under a Freedom of Information Request. The data were provided in raw digital form for many of the analytes of interest. In some cases, this required "zipping" and "unzipping" (methods to code and decode the data which minimizes storage space in the computer) the data which were obtained. In the case of gases for example, some of the analyses were performed every 15 seconds for twenty years and all raw data were provided. Where possible, geometric means were prepared for the Jacksonville data yearly and otherwise the data were provided in arithmetic mean summaries, which are used. Where appropriate, the difference is noted.

Similar data were obtained for the six priority pollutants in nine comparable U.S. cities and plots were prepared for each for the twelve years spanning 1979–1991, for which the data were available. Each priority pollutant will be discussed separately. It must be stated at the outset that the principal authors did not believe that air quality in Jacksonville is unreasonable for a city of its size and industry. The data confirmed that belief. A map of the United States is shown in Figure 1, indicating the location of the nine cities used for comparison to Jacksonville: Dayton, OH; Louisville, KY; Mobile, AL; New Orleans, LA; Norfolk, VA; Oklahoma City, OK; Oxnard, CA; Portland, OR; and Providence, RI. Three cities were located on the east coast, two on the west coast, and five in the interior.

Particulate matter—The concentration data for particulate matter in the nine cities is given (Fig. 2), and the appropriate Federal Standard maximum concentration is shown for comparison. The first observation is that in the early years of monitoring, compliance at all stations was erratic. Portland, OR, on the west coast was perhaps most out-of-compliance in the early to middle 1980s. The method of sample collection was changed in 1987 from the old TSP (total suspended particulates) to the PM-10 (the so-called inhalable particle concentration: particles smaller than 10 microns mass me-

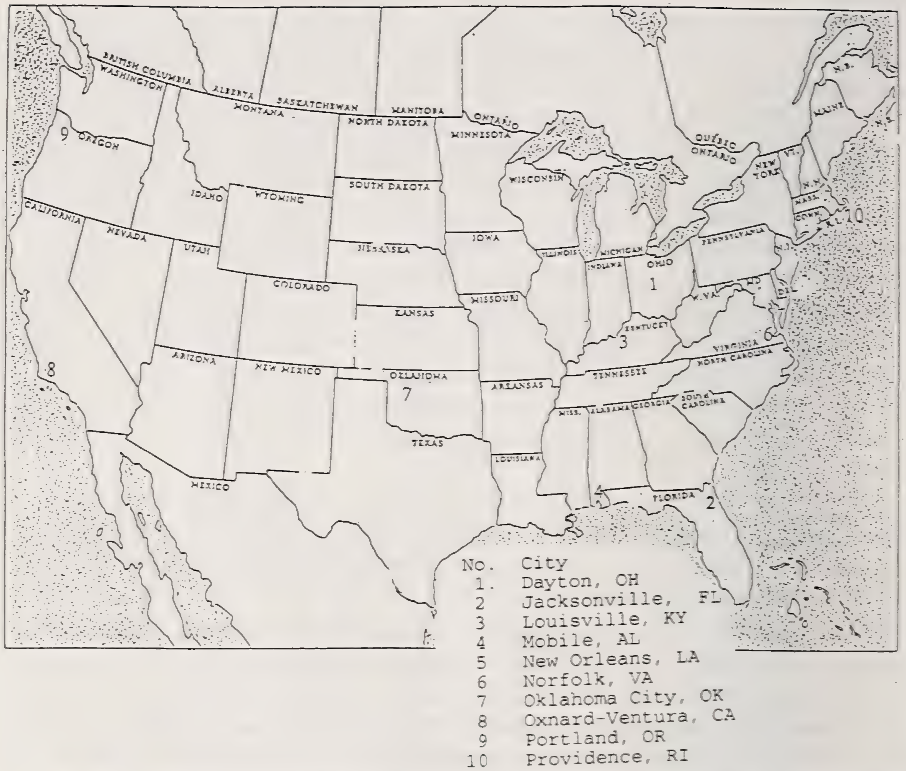


FIG. 1. Map of continental United States showing location of Jacksonville and other cities used for comparison to it.

dian diameter). The change was made because the larger particles are primary natural in origin as opposed to the smaller particles which are likely to have been produced from anthropogenic sources. Noticeably, *all* cities then fit the criterion, which was lowered from 75 micrograms per cubic meter to 50. Jacksonville's particulate concentration has trended steadily downward over the period, as have most of the other cities. The concentration seems to have stabilized at around 30 $\mu g/M^3$.

Lead—As shown (Fig. 3), lead concentrations were high in all urban air samples in the 1960s through the early 1980s due to the use of gasoline-powered road vehicles which used fuel enhanced with anti-knock agents containing lead. Lead was removed from gasoline with the introduction of the catalytic converter, which is poisoned by the lead (or phosphorus) in gasoline. After 1987, the concentrations of lead in all cities dropped dramatically. Similarly, lead blood levels in inner city children decreased as a result of lower air concentrations. The high concentrations observed in Jacksonville in the late 1970s may have been due to a local source of lead or

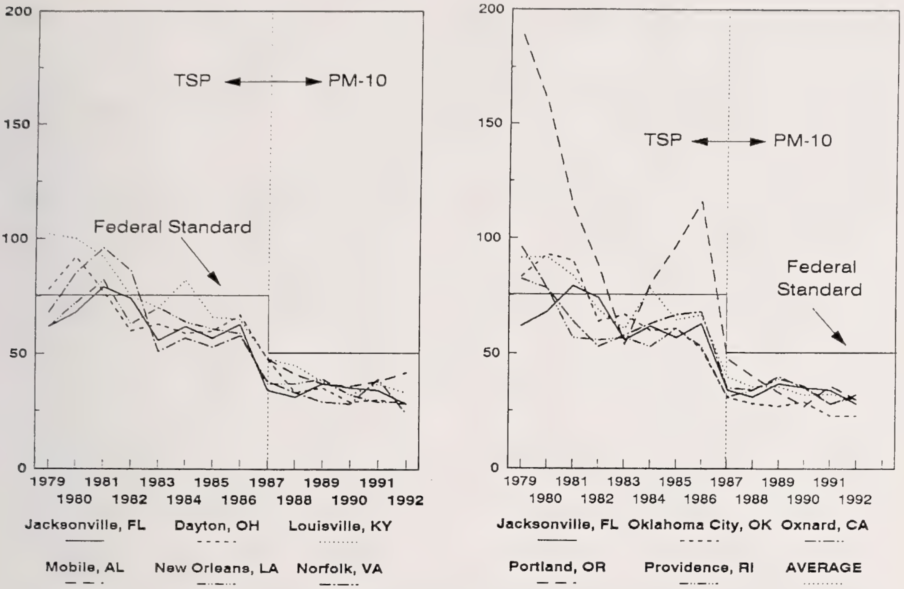


FIG. 2. Plot of the concentration of TSP (or PM-10) in micrograms per cubic meter, for the period from 1979–1992.

may be part of a national trend for the period. For an unknown reason, concentration of lead increased significantly in the early 1980s before falling to background levels late in the decade. This pattern is apparent in the Norfolk data, as well as for Portland and Providence. None of the authors are sufficiently conversant with lead studies to be able to comment on this apparent trend in most cities; however, a similar trend does not appear in the TSP/PM10 data (Figure 2).

TABLE 4. Air quality standards.

Pollutant	Averaging Time	Primary Standard	Florida Standard
SO_2	Annual arith. mean	30 ppb	20 ppb
	*24 hr	140 ppb	100 ppb
	3 hr		500 ppb
NO_2	Annual arith. mean	50 ppb	50 ppb
CO	*8 hr	9 ppm	9 ppm
	*1 hr	35 ppm	35 ppm
O_3	3-yr exceedance	not more than one per year	not more than one per year
	1 hr	120 ppb	120 ppb
Pb	Calendar Quarter	1.5 $\mu g/m^3$	1.5 $\mu g/m^3$
PM10	Annual arith. mean	50 $\mu g/m^3$	50 $\mu g/m^3$
	*24 hr	150 $\mu g/m^3$	150 $\mu g/m^3$

* Not to be exceeded >1/yr.

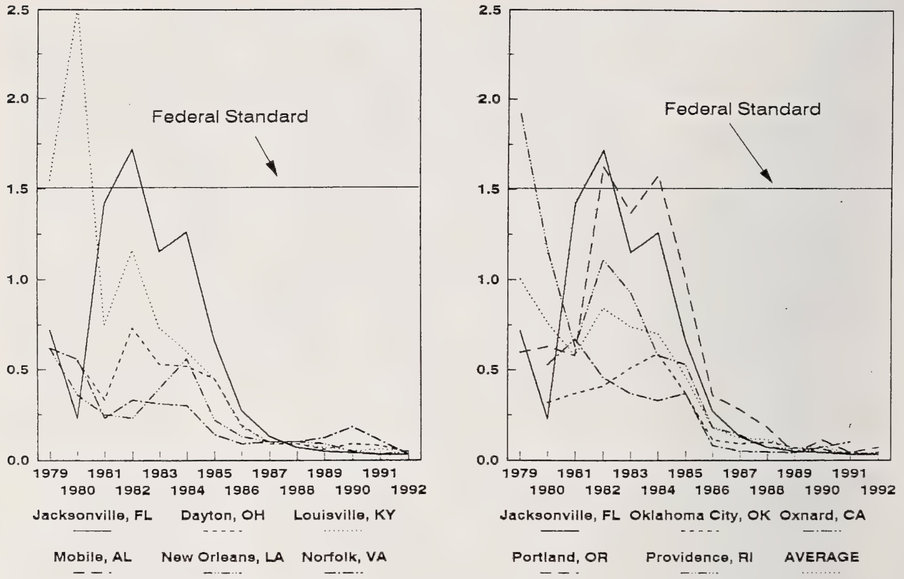


FIG. 3. Plot of the concentration of lead in micrograms per cubic meter, for the period from 1979–1992.

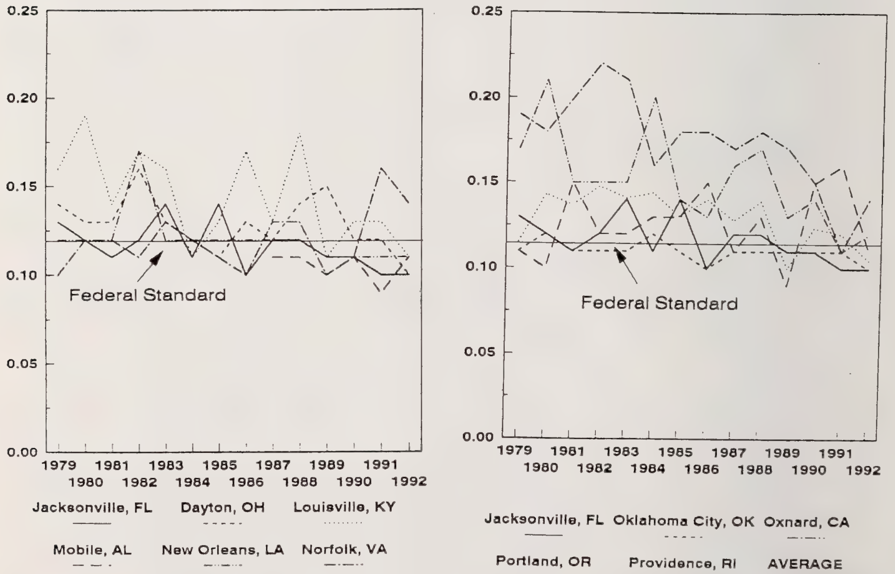


FIG. 4. Plot of the concentration of ozone in parts-per-million, for the period from 1979–1992.

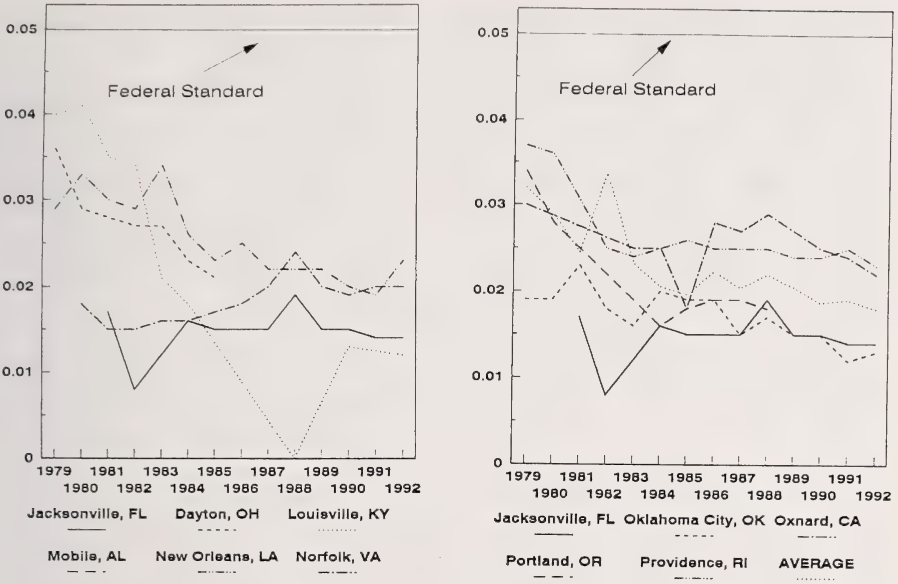


FIG. 5. Plot of the concentration of nitrogen dioxide in parts-per-million, for the period from 1979–1992.

Nitrogen dioxide—From the twelve year trend shown (Figure 5) it is apparent that none of the cities is in danger of exceeding the annual arithmetic average concentration limit of 50 ppb. The similarity of the plots for Jacksonville and Norfolk is also noted (Fig. 5). Concentrations in both cities increased in 1988 but returned in the following year. Missing data for 1988 carused the decrease shown in the Louisville, KY plot.

Sulfur dioxide (Fig. 6)—As noted in the historical record of air quality in Jacksonville, there was a problem with sulfur dioxide noted as far back as the 1940s. Past the left side of these graphs, it was recognized that efforts to reduce sulfur concentrations were required (the nylon stocking incident. A coordinated effort between government and industry reduced the concentration of sulfur oxides to the current levels. Norfolk data were not available for the early years; however, in recent times, concentrations there, while still within limits, are higher than in Jacksonville.

Carbon monoxide (Fig. 7)—A definite downward trend is observed for the combined cities shown. Compliance of Jacksonville air with Federal requirements is similar to other cities in meeting the limits established by the Federal government. The concentrations are lower in recent years than before 1987; introduction of catalytic converters on passenger vehicles probably is responsible for improvement in this category. Again, Jacksonville appears at the low end of this plot.

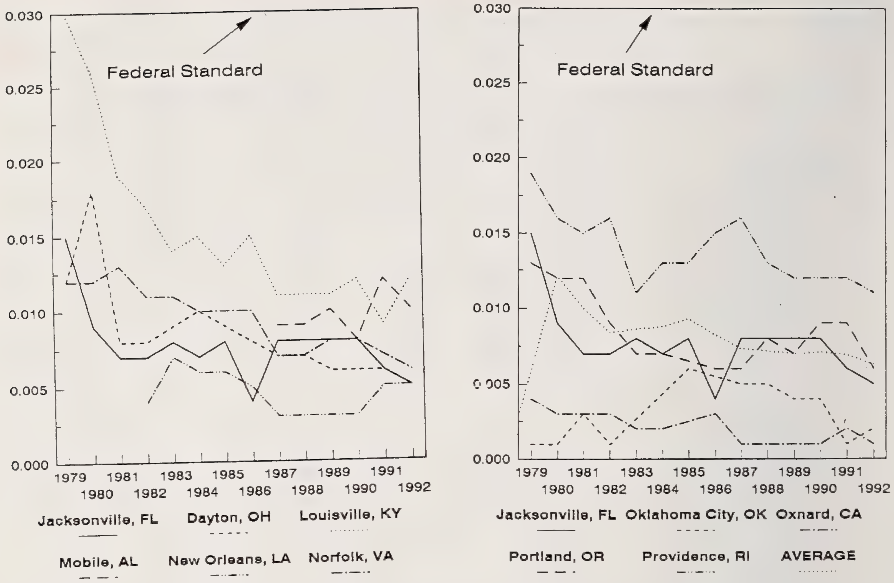


FIG. 6. Plot of the concentration of sulfur dioxide in parts-per-million, for the period from 1979–1992.

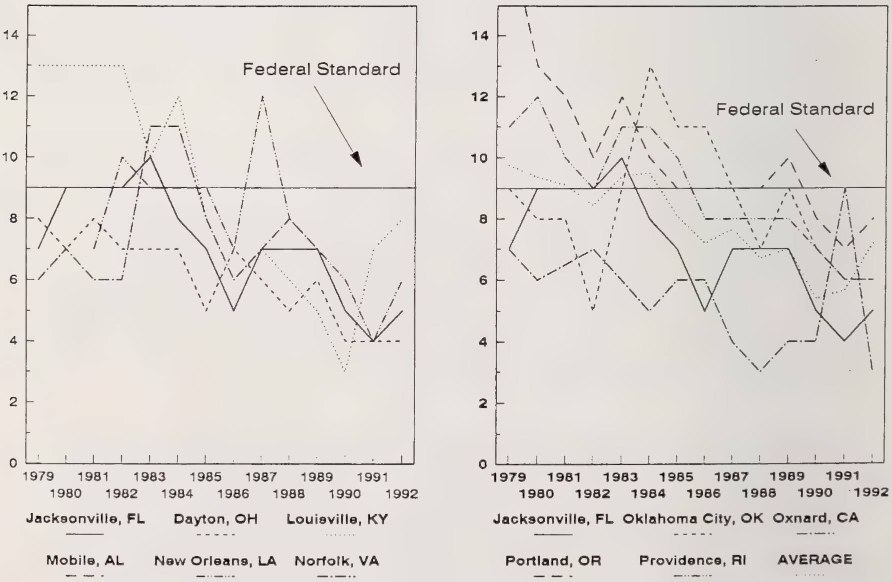


FIG. 7. Plot of the concentration of carbon monoxide in parts-per-million, for the period from 1979–1992.

Conclusions—Whereas Jacksonville's reputation of being a city with "bad air" has always been valid in some sense, concern over air quality has existed for over fifty years. During the five decades, Jacksonville had the highest or second highest lung cancer death rate (among white males) for large cities (SMA or SEA) in the Nation (Pickle et al., 1987), and at the same time it is shown in this paper to have been among the cleanest cities by EPA standards. The unknown chemical agent may not be one of the substances being studied; however, in spite of investigations over that period, no significant concentration of any actual single measured pollutant has ever been linked to lung cancer. While a link between air quality and lung cancer is not demonstrated, it can be said that air quality, as defined by the six criteria pollutants, cannot be linked to lung cancer, there is nothing which has been studied over the past fifty years which is close to the missing link, or "Factor X" as the popular press has named it.

Acknowledgments—This work was funded by a grand from the Duval County Lung Cancer Task Force, which is supervised by personnel from the Heart and Lung Institute at St. Vincent's Medical Center. Funds were obtained from the American Cancer Society, the American Lung Association, and the Environmental Protection Board of the city of Jacksonville. The Medical Library at St. Vincent's Medical Center has a full set of documents. Examination of the papers, reports, etc. can be arranged by calling the Library at (904) 308-8165. Arrangements can be made for copying at a reasonable rate if requested.

LITERATURE CITED

Allen, E. R., C. H. Liao, P. T. Karney and T. Brewer. 1985. Investigation of Odorous Emissions at a Jacksonville Wastewater Treatment Facility. Presented at: Annual Meeting, Florida Section, Air Pollution Control Association, September 29–October 1, 1985.

Anonymous. 1965. Greater Jacksonville Air Pollution Control Program- Quarterly Progress Report. October 1 1964-December 31, 1964. Air Pollution Research Laboratory, Engineering and Industrial Experiment Station, University of Florida, Gainesville, FL, January 31, 1965.

———. 1970. Emission Inventory of Air Pollutants in the City of Jacksonville, FL.

———. 1993. "Pollution, Pollution. . .". Sci. Am. 268: 23–24.

Barzyk, T., A. Luther, and J. Woosley. 1987. Assessment of Stage I Vapor Control Technology Application in Duval County.

Blot, W. J., J. E. Davies, L. M. Brown, C. W. Nordwall, E. Buiatti, A. Ng, and J. F. Fraumeni. 1982. Occupation and the high risk of lung cancer in Northeast FL. Cancer 50: 364–371.

Butcher, J. T. and R. D. Delumyea. 1991. Impact of toll removal on air particulate concentration in Jacksonville, Florida. J. Air Waste Manage. Assoc. 41: 1601–1604.

Delumyea, R. D, T. McKay, and J. Horowitz. 1997. A search for the source of high lung cancer in Northeast Florida. I. Literature Search for Air Quality Studies Conducted in Jacksonville, Florida, 1945–1995. Florida Scient., 60: 166–174.

Environmental Science and Engineering, Inc. 1979a. Citizen Complaint Summary, Odor Abatement Study. Prepared for: City of Jacksonville, Department of Health, Welfare and Bio-Environmental Services Division, Jacksonville FL. Submitted by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-001, November, 1979.

———. 1979b. Summarization of Citizen Questionnaire Results, Odor Abatement Study. Jacksonville, FL. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL and PLANTEK CORP. Jacksonville, FL ESE Document #: 78–147, March, 1979.

———. 1979c. Analytical Results Characterizing the Twenty- Four Hour Variation of Volatile Organics at Site 3-Odor Abatement Study. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003, September 28, 1979.

———. 1979d. Analytical Results Characterizing Volatile Organics in the Ambient Air Near Suspected Odor Sources-Odor Abatement Study. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003, November, 1979.

———. 1979e. Odor and Toxicity Ratings of Airborne Volatile Organic Compounds-Odor Abatement Study. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Prepared by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003, November 28, 1979.

———. 1979f. Sampling and Analysis of Volatile Organic Compounds for the Odor Abatement Study, Jacksonville, FL. Prepared for: City of Jacksonville, Bio-Environmental Services Division, Jacksonville FL. Submitted by: Environmental Science and Engineering, Inc. Gainesville, FL. ESE Document #: 78-147-003, November, 1979.

———. 1980. Project Summary Report—Odor Abatement Study. Prepared for: City of Jacksonville, Department of Health, Welfare, and Bio-Environmental Services Division. Submitted by: Environmental Science and Engineering, Inc. Gainesville, FL Document Number 78-147-001, January, 1980.

ERFANI-EZATI, G. 1984. Measuring the Benefits From Air Pollution Abatement on Human Health and Welfare: A Case Study of Jacksonville, FL. Ph. D. Dissertation, Department of Economics, The Florida State University, Tallahassee, FL, August 1984.

FAYSON, N. 1986. Toll Collection-Matthews Bridge; A Consultative Health Survey. DOT Reference # J86-8002 HP, April 10, 1986.

GRENIER ENVIRONMENTAL SCIENCES, INC. 1974a. Development of Regional Impact Application for Development Approval and Complex Source Permit for the Bay Meadows Shopping Mall Jacksonville—Duval County, Florida. Prepared by: Grenier Environmental Sciences, Inc. Prepared for: Edward J. DeBartolo Corp, June, 1974.

———. 1974b. Seven Day Carbon Monoxide Monitoring Results and Findings Required as Part of Complex Source Permit Application for The Baymeadows Shopping Mall Jacksonville-Duval County, Florida. Prepared by: Grenier Environmental Sciences, Inc. Prepared for: Edward J. De Bartolo Corp, July, 1974.

HARDING, C. I., S. B. MCKEE, AND J. J. SCHUENEMAN. 1961. A Report on Florida's Air Resources. Prepared by: Bureau of Sanitary Engineering, Florida State Board of Health. Submitted to: Florida State Board of Health, Jacksonville, Florida, February, 1961.

———, A. L. DANIS, AND J. B. KOOGLER. 1967. Greater Jacksonville Air Pollution Control Program. Final Progress Report. Bioenvironmental Engineering Dept, College of Engineering, University of Florida, Gainesville, FL, August, 1966.

HENNEKENS, C. H., J. E. DAVIES, R. S. LEVINE, F. W. BRIESE, AND C. W. NORDWALL. 1981. Trends of Lung Cancer in Northern Florida. South. Med. J. 74: 566–568.

HORM, J. W., A. J. AMIRE, J. L. YOUNG, JR. AND OTHERS. 1984. Seer Program: Cancer Incidence and Mortality in the United States, 1973–81. Bethesda, Md.: U. S. Department of Health and Human Services. Publication No. NIH 85-1837.

JACKSONVILLE COMMUNITY COUNCIL, INC. 1988. Life in Jacksonville—Quality Indicators for Progress. Prepared for: The Jacksonville Chamber of Commerce. Prepared by: Jacksonville Community Council, Inc., November, 1988.

JACKSONVILLE ELECTRIC AUTHORITY. 1982. Environmental Impact Statement. Jacksonville Electric Authority, St. Johns River Power Park. EPA 904/9-82-096.

MEHTA, K. K., W. E. TUTT, D. SWARTZ, L. HUNTER, AND BESD PERSONNEL. 1985a. The Initial Strategies and Development of the Air Toxics Program for the City of Jacksonville, FL.

Prepared by: Department of Health, Welfare and BioEnvironmental Services, Bio-Environmental Services Division, City of Jacksonville, Jacksonville FL. Presented: 1985 Annual Conference, Florida Air Pollution Control Association, St. Augustine, FL. September 29–October 1, 1985.

———, W. E. TUTT, R. BASKIN, D. SWARTZ, AND L. HUNTER. 1985b. A Comparative Study of Select Organic Sulfur Compounds in the Wastewater at Two Organic Chemical Companies and at The Buckman Street Sewage Plant. Presented: 1985 Annual Conference, Florida Air Pollution Control Association, St. Augustine, FL. September 29–October 1, 1985.

MULLINS, B. M. 1978. Geochemical Aspects of Atmospherically Transported Trace Metals Over the Georgia Bight. Master's Thesis, Department of Geophysical Engineering, Georgia Institute of Technology, Atlanta, GA, May, 1978.

PEDCO ENVIRONMENTAL SPECIALISTS, INC. 1975. Particulate and Sulfur Dioxide Area Source Emission Inventory for Duval, Hillsborough, Pinellas and Polk Counties, Florida, Volume I Prepared by: PEDCo-Environmental Specialists, Inc. Suite 13, Atkinson Square, Cincinnati, OH 45246. Contract No. 68-02-1375, Task Order No. 95PN 3155-I. Prepared for: U.S. Environmental Protection Agency, Region IV, Air Programs Branch, Atlanta, GA 30309, November, 1976.

PFETZING, E. 1976. Air Quality Modeling in Jacksonville, FL. Volume I. Prepared by: PEDCo-Environmental Specialists, Inc. Suite 13, Atkinson Square, Cincinnati, OH 45246. Contract No. 68-02-1375, Task Order No. 24. Prepared for: U.S. Environmental Protection Agency, Region IV, Air Programs Branch, Atlanta, GA 30309, and Florida Department of Environmental Regulation, Tallahassee, FL 32301. November, 1976.

POPE, C. A. 1989. Respiratory disease associated with community air pollution and a steel mill, Utah Valley. Amer. J. Pub. Health 79: 623–628.

———. 1991. Respiratory hospital admissions associated with PM-10 pollution in Utah, Salt Lake and Cache Valleys. Arch. Environ. Health 46: 90–97.

———, AND D. W. DOCKERY. 1992. Acute health effects of PM-10 pollution on symptomatic and asymptomatic children. Amer. Rev. Resp Health 45: 1123–1128.

———, D. W. DOCKERY, AND J. D. SPENGLER, 1991. Respiratory health and PM-10 pollution. A daily time series analysis. Amer. Rev. Respir. Disease 114: 668–674.

———, J. SCHWARTZ AND R. RANSOM. 1992. Daily mortality and PM-10 pollution in Utah Valley. Arch. Environ. Health 47: 211–217.

RANSOM, M. R. AND C. A. POPE. 1992. Elementary school absences and PM-10 pollution in Utah Valley. Environ. Res. 58: 204–219.

REICHHARD, T. 1995. Weighing the health risks of airborne particulates. Environ. Sci. Tech. 29: 360–364.

SHEEHY, J. P., J. J. HENDERSON, C. I. HARDING, AND A. L. DANIS. 1963. A Pilot Study of Air Pollution in Jacksonville, FL.

SHELLHORN, J. 1987. Report on CO Special Studies Fuller Warren and Matthews Bridge Toll Areas Jacksonville, FL.

TUTT, W. E. 1989. Setting an Ambient Odor Standard. Presented, 82nd Annual Meeting and Exhibition, Air Pollution Control Association, Anaheim, California, June 25–30, 1989.

———. 1991a. Successful Application of Odor Control Technology at a Polyester Resin Manufacturing Facility. Presented at the 84th Annual Meeting and Exhibition, Vancouver, British Columbia, June 16–21, 1991.

———. 1991b. A Regulatory Approach for Controlling Odors in The Terpene Chemical Manufacturing Industry.

WILSON, A. L. 1971. An Atmospheric Diffusion Model for Jacksonville, FL. M. S. Thesis, Department of Engineering, University of Florida, Gainesville, FL.

WINCHESTER, J. W. 1987. Air Pollution Sulfuric Acid Reactivity and Lung Cancer Risk in Florida (Final Research Grant Report to The American Lung Association of Florida with a Summary of Findings from Prior Year Grant Air Quality and Epidemiology of Lung Cancer in Florida).

———. 1989. Regional Anomalies in Chronic Obstructive Pulmonary Disease; Comparison with Acid Air Pollution Particulate Characteristics. Arch. Environ. Toxicol. 18: 291–306.

ZAEBST, D. D. 1989. In Depth Survey Report of P-I-E Nationwide, Inc. PB90-130055, Department of Commerce, April, 1988.

Florida Scient. 60(3): 175–192. 1997
Accepted: March 4, 1997.

UTILITY OF A CAMERA SYSTEM FOR INVESTIGATING GOPHER TORTOISE BURROWS

Donald M. Kent[1], Michael A. Langston[2], David W. Hanf[2], and Peter M. Wallace[3]

(1)WDI-Cambridge, 101 Rogers Street, Suite 304, Cambridge, MA 02142
(2)Azurea, Inc., 414 Richard Road, Suite 1, Rockledge, FL 32956
(3)Ecosystem Research Corporation, 2906 NW 142nd Avenue, Gainesville, FL 32609

Abstract: *Recent advances in camera technolgy offer the potential for using camera systems to quickly and accurately investigate gopher tortoise (*Gopherus polyphemus*) burrows. The results of an investigation of two preserve sites are presented here to illustrate the utility of one camera system. The camera system was able to confirm the status of 97 percent of the burrows (n=208). Burrow size did not pose a constraint to investigation. An average of 30 minutes was required to set-up the system, investigate the burrow, and dismantle the system. Compared to burrow activity status assignments based upon observations of the burrow entrance, the camera system observed fewer burrows to be active and more burrows to be abandoned. All burrow commensals encountered by the camera were identified (to major groups in the case of invertebrates). The camera system has demonstrated utility for accurately censusing gopher tortoise and burrow commensals. Indirect tortoise population estimation methods are more appropriate when accuracy is not critical and time is a factor.*

Estimation of gopher tortoise (*Gopherus polyphemus*) populations and investigations of gopher tortoise burrows have historically been accomplished using observations of the burrow entrance, bucket trapping, and excavation (Cox et al., 1987). Camera systems are thought to offer great potential for censusing gopher tortoise and burrow commensals (Cox et al., 1987), but have received little use (Spillers and Speake, 1986; Breininger et al., 1988 and 1991; Burke, 1992). Prior users have found that camera systems require more time than indirect population estimation techniques, considerable down time for equipment maintenance, and that cameras were ineffective for small or flooded burrows (Spillers and Speake, 1986; Breininger et al. 1988 and 1991; Burke, 1992). Nevertheless, camera systems are quicker than bucket trapping or excavation for censusing tortoises, are nondestructive, can be used at any time of the year, and can potentially be effective for investigating burrow commensals.

Recent advances in camera technology offer the potential for overcoming many of the disadvantages attributed to existing camera systems. We have been using a Machida Flexible Boroscope to investigate gopher tortoise and other burrows since 1993. The results of an investigation of two gopher tortoise preserve sites is described here to illustrate the utility of the system. The investigation included a comparsion of the number of tortoises observed with the camera system with estimates derived from the number of burrows (Auffenberg and Franz,1982; Cox et al., 1987; McCoy and Mushinsky, 1992) so that the relative merits of each approach could be evaluated for these sites.

STUDY AREA—The preserve sites are located in Lake Buena Vista, Orange County, Florida. The sites encompass 9.3 ha (Site 1) and 10.9 ha (Site 2) and were historically orange grove. Orange trees were removed about seven years ago and the preserves are now old field habitat. Slash pine (*Pinus* elliotti) was planted on Site 2 five years ago at a density of about 1000 per ha. Some trees have subsequently been removed. Herbaceous vegetative cover is 25 to 30 percent at each site, and is dominated by bahiagrass (*Paspalum notatum*), natalgrass (*Rhynchelystrum repens*), and ragweed (*Ambrosia* sp.)

METHODS—The camera system consists of a Panasonic Industrial Super-Micro 0.9 cm diameter, waterproof, CCD Color Camera with a 7 m-long cable. A mechanical control located at the proximal end of the cable allows the operator to move the distal 20 cm of the cable vertically and horizontally. The light source (Machida model RH-150A5), with a variable intensity control, provides up to 150 W of light via a fiber optic strand to a narrow ring surrounding the camera. The monitor (MPO Videotronics) combines a high resolution screen with a VHS video cassette recorder. Power for this study was provided by a 1200 W gasoline-powered generator transported in a truck or all-terrain vehicle.

Tortoise burrows were assigned a burrow activity status based upon visual observation of the burrow entrance (Auffenberg and Franz,1982; Cox et al., 1987; McCoy and Mushinsky, 1992) and subsequently investigated with the camera system. Ninety three burrows were assigned a status at Site 1 on 24 June 1994, and investigated with the camera system from 24 June through 12 July 1994. One hundred fifteen burrows were assigned a burrow status at Site 2 based upon visual observation of the burrow entrance on 5 July 1994, and investigated with the camera system from 6 through 21 July 1994.

The numbers of gopher tortoises observed with the camera system were compared with indices derived from observations of the burrow entrances. The Auffenberg and Franz (1982) index applies a correction factor to the number of active and inactive burrows, and is the standard method for converting number of burrows to number of tortoises. More recently McCoy and Mushinsky (1992) have suggested that the linear regression of log number of tortoises on log number of active burrows is a reliable way to predict number of tortoises from number of burrows.

RESULTS AND DISCUSSION—The camera system was able to confirm the status of 202 of 208 (97%) of the burrows. In four of six instances, burrow length exceeded the length of the camera. In one instance an apparently active burrow collapsed prior to completing the investigation, and in another instance the camera could not negotiate one especially sinuous burrow. Burrow width (6 to 39 cm) had no affect on camera use.

An average of about 30 minutes (range 15 to 90 minutes) was required to investigate a burrow, including the time taken to set-up and dismantle the camera system. Less time was required for short, relatively straight burrows than for long, sinuous burrows and burrows containing many roots. Efficiency was improved by locating the power source and camera system central to several burrows. Breininger and co-workers (1988) report that surveying a burrow took 3 to 20 minutes with an average of 10 minutes, but this does not include time required to set-up and dismantle the system.

TABLE 1. Comparison of gopher tortoise burrow status based upon observations of the burrow entrance and camera system investigations at two sites in Lake Buena Vista, Orange County, Florida.

	Site 1		Site 2	
Burrow Status	Entrance Observation	Camera	Entrance Observation	Camera
Active	48	41	48	39
Inactive	30	21	28	19
Abandoned	15	30	39	52
Unable to Confirm	—	1	—	5

The camera system documented 41 tortoises at Site 1 and 39 tortoises at Site 2 (Table 1). Fewer burrows were found to be active and more were found to be abandoned by the camera than were estimated from observation of the burrow entrance. These differences resulted in discrepancies between the observed number of gopher tortoises and estimates of the tortoise population using various indices (Table 2). The Auffenberg and Franz index (1982) predicted tortoise populations 17 and 21 percent greater than were observed. By contrast, the McCoy and Mushinsky (1992) indices dramatically underestimated (51 to 62 percent) the size of the populations. Differences between the observed number of tortoises and the estimated number of tortoises reflects the margin of error associated with these indices.

The camera system identified 23 vertebrate commensals, including southern toad (*Bufo terrestris*), gopher frog (*Rana capito*), coachwhip (*Masticophis flagellum*), scrub lizard (*Sceloporus woodi*), cotton mouse (*Peromyscus gossypinus*), and numerous invertebrates including spiders, ants, flies, wasps, crickets, and beetles. Three scrub lizards and one coachwhip were recorded using burrows during observations of the burrow entrance.

The results of this study illustrate the advantages of this camera system for investigating gopher tortoise burrows. The camera system was able to completely census nearly 100 percent of gopher tortoise burrows in less time than is required by bucket trapping or excavation. Even small burrows could be censused without difficulty, and there was no system down time. Without

TABLE 2. Observed and estimated gopher tortoise populations at two sites in Lake Buena Vista, Orange County, Florida. Tortoises were observed with a camera; estimates derive from observations of the burrow entrance. A = active burrow, I = inactive burrow.

Method	Site 1	Site 2
Camera	41	39
# tortoises = (0.614) (A + I)*	48	47
log # tortoises = −0.301 + (0.998) (log # A)**	24	24
log # tortoises = −0.351 + (0.883) (log # A + I)**	21	20

* Auffenberg and Franz 1982.
** McCoy and Mushinsky, 1992.

altering the burrow, the camera system provided a direct count of the population. As use of the camera does not require the tortoises to be active, it can be used at any time of the year.

Perhaps the greatest advantage of the camera system is its ability to locate and identify burrow commensals, again without altering the burrow. During this study and other investigations of burrow commensals (Kent et al., in press), we have been able to identify virtually all organisms present in the burrow either at the time of investigation or later during review of the videotape. Investigations of seasonal and diurnal commensals may require repeat or nocturnal sampling to ensure accurate censusing. In our experience, commensal mice are best censused by inserting the camera into the main mouse burrow entrance rather than attempting to access tunnels intersecting with tortoise burrows.

The use of a camera system is more time consuming than observing the burrow entrance for signs of activity. In instances when accuracy is not critical, and time is a factor, observation of burrow entrance activity and use of an index is a more appropriate method for estimating gopher tortoise populations.

ACKNOWLEDGMENTS—We thank Annette Paulin, Mark Roberts, and Dan Rich for help with the field work, and Tom DeBusk, Craig Duxbury, and an anonymous reviewer for comments on an earlier version of this manuscript. Funding for this project was provided by Walt Disney Research and Development and the Reedy Creek Improvement District.

LITERATURE CITED

AUFFENBERG, W. AND R. FRANZ. 1982. The status and distribution of the gopher tortoise (*Gopherus polyphemus*). Pp. 95–126. *In* R. B. Bury (ed.), North American Tortoises: Conservation and Ecology. U. S. Fish and Wildlife Service Research Report 12.

BREININGER, D. R., P. A. SCHMALZER, D. A. RYDENE, AND C. R. HINKLE. 1988. Burrow and habitat relationships of the gopher tortoise in coastal scrub and slash pine flatwoods on Merritt Island, Florida. Florida Game and Fresh Water fish Comm. Nongame Wildl. Program Final Rep. 238 pp. + x.

———, P. A SCHMALZER, AND C. R. HINKLE. 1991. Estimating occupancy of gopher tortoises (*Gopherus polyphemus*) burrows in coastal scrub and slash pine flatwoods. Journal of Herpetology 25(3):317–321.

BURKE, R. L. 1992. Multiple occupancy. Natural History June, 1992.

COX, J., D. INKLEY, AND R. KAUTZ. 1987. Ecology and habitat protection needs of gopher tortoise (*Gopherus polyphemus*) populations found on lands slated for large-scale development in Florida. Florida Game and Fresh Water Fish Commission, Nongame Wildlife Program Technical Report 4.

KENT, D. M., M. A. LANGSTON, AND D. W. HANF. 1997. Observations of vertebrates associated with gopher tortoise burrows in Orange County, Florida. Florida Scient. 60(3):198–202.

MCCOY, E. D. AND H. R. MUSHINSKY. 1992. Studying a species in decline: Gopher tortoises and the dilemma of "correction factors". Herpetologica 48(4):402–407.

SPILLERS, D. M., AND D. W. SPEAKE. 1986. Status and distribution of the gopher tortoise (*Gopherus polyphemus*) in southern Alabama. Report to U.S. Fish and Wildlife Service, Jackson, MS. 24 pp.

Florida Scient. 60(3): 193–196. 1997
Accepted: January 15, 1997.

OBSERVATIONS OF VERTEBRATES ASSOCIATED WITH GOPHER TORTOISE BURROWS IN ORANGE COUNTY, FLORIDA

Donald M. Kent(1), Michael A. Langston(2), and David W. Hanf(2)

(1)WDI-Cambridge, 101 Rogers Street, Suite 304, Cambridge, MA 02142
(2)Azurea, Inc., 414 Richard Road, Suite 1, Rockledge, FL 32956

Abstract: *A total of 414 gopher tortoise (*Gopherus polyphemus*) burrows on 11 separate sites in Lake Buena Vista, Orange County, Florida were investigated using a camera system to add to our understanding of the vertebrate commensal community. One hundred sixteen vertebrates of seven species were observed. A commensal was located, on average, in one of every 3.6 burrows. Eighty six percent of observed commensals were gopher frogs (*Rana capito*), which were observed on average in one of every 4.1 burrows. Gopher frogs were equally likely to be found in active and inactive burrows and less likely to be found in abandoned burrows. Remaining species were equally frequent in active, inactive, and abandoned burrows. Effects of local and landscape characteristics on the commensal community were evident, but no significant correlations were detected between the number of commensals and the size of the site, number of burrows on a site, burrow density, or the distance to water suitable for amphibian breeding.*

It is well known that many invertebrate and vertebrate species use gopher tortoise (*Gopherus polyphemus*) burrows for refuge, nesting, and to feed on fecal matter or on other burrow associates (Speake, 1981, Campbell and Christman, 1982; Woodruff, 1982; Eisenberg, 1983; Jackson and Milstrey, 1989). Less well understood are the frequency of occurrence of different commensal species in the burrows, the relationship between burrow status and commensal use, and the effects of local and landscape characteristics on the occurrence of commensals in gopher tortoise burrows (Eisenberg, 1983; Lips, 1991; Witz et al., 1991; Kent and Snell, 1994). The results of an investigation of gopher tortoise burrows are presented here to add to our understanding of the factors which affect the burrow commensal community. A better understanding of these factors would improve land management decision-making.

Study Area—The investigation was conducted in southwest Lake Buena Vista, Orange County, Florida. Eleven separate sites, including both modified and unmodified habitats, were investigated for vertebrate commensals (Table 1). Sites ranged in size from 0.4 to 97.2 ha.

Methods—A total of 414 gopher tortoise burrows were investigated 29 March to 5 August, 1994. Burrows were investigated with a Machida Flexible Boroscope camera system which can examine burrows up to 7.3 m in length. The camera system consists of a Panasonic Industrial Super-Micro 0.9 cm diameter CCD Color Camera attached to the distal end of a 7 m

TABLE 1. Vertebrates identified in gopher tortoise burrows in Lake Buena Vista, Orange County, Florida.

Site Number	Habitat	Size (ha)	Sample Date(s) (d/m/y)	Number of Burrows	Commensal	Number of Individuals
1	old field and planted eucalyptus	2.8	29/03/94	11	gopher frog[1]	8
2	mowed grass	14.2	29/03/94–27/04/94	8	gopher frog	10
					southern toad[2]	1
					six-lined racerunner[3]	1
3	cow pasture	57.5	26/04/94–23/06/94	60	gopher frog	55
4	xeric oak scrub and scrubby flatwood	97.2	26/04/94–2/8/94	48	gopher frog	15
					pine snake[4]	1
5	xeric oak scrub and flatwoods	13.4	27/04/94	5	—	—
6	xeric oak scrub and flatwoods (subject to prescribed burn)	8.5	27/04/94–18/05/94	16	—	—
7	old field and planted oak	10.9	24/06/94–5/8/94	107	southern toad	2
					scrub lizard[5]	2
					cotton mouse[6]	1
8	old field and planted pine	9.3	06/07/94–5/8/94	129	gopher frog	6
					southern toad	4
					eastern coachwhip[7]	3
9	xeric oak scrub	2.8	13/07/94–2/8/94	16	gopher frog	3
10	old field	0.4	4/8/94	7	—	—
11	old field	29.1	5/8/94	7	gopher frog	3
					unidentified frog	1
Total				414		116

[1] *Rana capito,* [2] *Bufo terrestris,* [3] *Cnemidophorus sexlineatus,* [4] *Pituophis melanoleucus,* [5] *Sceloporus woodi,* [6] *Peromyscus gossypinus,* [7] *Masticophis flagellum.*

long cable. A mechanical control located at the proximal end of the cable allows the operator to move the distal 20 cm of the cable vertically and horizontally. The light source (Machida model RH-150A5) has a variable intensity control and provides up to 150 W of light via a fiber optic strand to a narrow ring surrounding the camera. The monitor (MPO Videotronics) combines a high resolution screen with a VHS video cassette recorder. Power was provided by a 1200 W gasoline-powered generator transported in a truck or all-terrain vehicle.

To allow comparison with earlier studies, burrows were designated active if a gopher tortoise was observed, inactive if no tortoise was observed but the burrow was maintained, and abandoned if no tortoise was observed and the burrow was not maintained (Auffenberg and Franz, 1982; Cox et al., 1987; McCoy and Mushinsky, 1992). The status of eight burrows could not be confirmed because their length exceeded the reach of the camera.

The frequency of commensal occurrence is the number of commensals observed divided by the number of burrows investigated. The significance of a relationship between burrow status and burrow occupancy was determined using the Test of Association (Ludwig and Reynolds, 1998). The effect of local (site size, number of burrows on a site, site burrow density) and landscape (distance to water suitable for amphibian breeding) factors on the number of commensals observed on a site was examined using Spearman Rank Correlation (Velleman, 1992). Water suitable for amphibian breeding is defined as a fish-free, seasonal or permanent waterbody. Distance to suitable waterbodies was determined by measuring the distance from the center of each site to the edge of the nearest waterbody on a local land use map.

RESULTS AND DISCUSSION—One hundred sixteen individuals of seven species of vertebrates were observed in gopher tortoise burrows (Table 1). No new vertebrate commensal species were identified.

A commensal was located, on average, in one of every 3.6 burrows. No commensals were observed on two of the scrub sites (21 burrows examined) and one of the old field sites (7 burrows examined). For those sites on which commensals were identified, frequency of occurrence ranged from one per 0.7 burrows (Site 2, mowed grass) to one per 21.4 burrows (Site 7, old field with planted oak). Previously reported frequencies of occurrence of vertebrates in burrows include one per 3.0 to 36.8 burrows (sandhill, Eisenberg 1983) one per 10 burrows (sandhill, Witz et al., 1991), and one per 5.2 burrows (xeric oak and sand pine, Kent and Snell, 1994).

Eighty six percent (n = 100) of observed commensals were gopher frogs (*Rana capito*), which occurred singly (40 burrows), in pairs (12 burrows), and in groups of three (5 burrows), four (4 burrows), and five (1 burrow) . In three burrows, a single gopher frog was observed with a single southern toad (all other commensals were observed individually). Gopher frogs averaged one per 4.1 burrows, but were not observed on sites 5, 6, 7, and 10. For sites on which frogs occurred, frequency of occurrence ranged from one per 0.8 burrows (Site 2, mowed grass) to one per 21.5 burrows (Site 8 old field and planted pine).

Seventy six burrows (18.4 percent) had one or more commensals, and 73 of these were reliably designated as active, inactive, or abandoned. Among the latter group, gopher frogs (N = 99) were equally likely to be found in active and inactive burrows ($\chi^2 = 0.89$, 1 df, $0.500 > p > 0.250$). This contrasts with earlier studies that found gopher frogs more likely to occur in active burrows (Eisenberg, 1983; Witz et al., 1991; Kent and Snell, 1994). Gopher frogs were less likely to be found in abandoned burrows than active burrows ($\chi^2 = 13.79$, 1 df, $p < 0.005$) or inactive burrows ($\chi^2 = 20.60$, 1 df, $p < 0.005$).

Of the remaining 16 vertebrate commensals observed, 13 were observed in burrows reliably assigned an activity status. No association between commensal occurrence and burrow status was detected ($\chi^2 = 1.96$, 2 df, $0.500 > p > 0.250$). Given the small sample size this conclusion should be considered tentative. Nevertheless, this finding is consistent with the findings of Kent and Snell (1994) that vertebrates occurred equally in active and inactive burrows, and Witz and co-workers (1991) that mammalian and amphibian commensals used active, inactive, and abandoned burrows equally. In contrast, Lips (1991) observed greater use of active burrows than inactive burrows. A difference in dominant species among the studies may account for the varying conclusions.

The effect of local characteristics on the commensal community in this study was evidenced by between-habitat differences in commensal abundance, richness, and community composition. Of note was the relatively high value for ruderal and other man-modified lands. No significant correlations occurred between the number of commensals on a site and size of the site ($r = 0.60$, $p = 0.36$), number of burrows on a site ($r = 0.62$, $p = 0.95$), or site burrow density ($r = -0.10$, $p = 0.64$). A landscape effect on the commensal community was evident, as commensal abundance, richness, and community composition varied among sites of the same habitat type. The distance to water suitable for amphibian breeding was not identified as a significant factor relative to abundance or species composition of commensals (Spearman Rank Correlation, $r = 0.61$, $p = 0.87$).

In summary, it is becoming clear that active, inactive, and abandoned gopher tortoise burrows are all important to commensals. Gopher frogs prefer active burrows, and, according to this study, inactive burrows to abandoned burrows. It is also clear that the commensal community varies considerably from habitat to habitat, and from site to site of the same habitat type. The factors responsible for these differences remain unclear, although it is likely that local and landscape characteristics act synergistically to determine the commensal community.

ACKNOWLEDGMENTS—We thank Annette Paulin and Mark Roberts for help with the field work, and I. Jack Stout, Tom DeBusk, Craig Duxbury, and an anonymous reviewer for comments on an earlier version of this manuscript. Funding for this study was provided by Walt Disney Imagineering Research and Development.

LITERATURE CITED

AUFFENBERG, W. AND R. FRANZ. 1982. The status and distribution of the gopher tortoise (*Gopherus polyphemus*). Pp. 95–126. *In:* North American Tortoises: Conservation and Ecology. Wildlife Research Report 12. U. S. Fish and Wildlife Service, Washington, D. C.

CAMPBELL, H. W. AND S. P. CHRISTMAN. 1982. The herpetological components of Florida sandhill and sand pine scrub associations. Pp. 163–171. *In:* Scott, N. J. (ed.). Herpetological Communities. U. S. Fish and Wildlife Service, Wildlife Research Report 13.

Cox, J., D. Inkley and R. Kautz. 1987. Ecology and habitat protection needs of gopher tortoise (*Gopherus polyphemus*) populations found on lands slated for large-scale development in Florida. Florida Game and Fresh Water Fish Commission Nongame Wildlife Program Technical Report No. 4, Tallahassee.

Eisenberg, J. F. 1983. The gopher tortoise as a keystone species. Pp. 1–4. *In:* Bryant, R. J. and R. Franz (eds.). The Gopher Tortoise: A Keystone Species. Proceedings 4th Annual Meeting Gopher Tortoise Council. Florida State Museum, Gainesville, FL.

Jackson, D. R. and E. G. Milstrey. 1989. The fauna of gopher tortoise burrows. Pp. 86–98. *In:* J. E. Diemer, D. R. Jackson, J. L. Landers, J. N. Layne, and D. A. Wood (eds.). Gopher Tortoise Relocation Symposium Proceedings. Florida Game and Fresh Water Fish Commission. Nongame Wildlife Program Technical Report #5.

Kent, D. M. and E. Snell. 1994. Vertebrates associated with gopher tortoise burrows in Orange County, Florida. Florida Field Natur. 22(1): 8–10.

Lips, K. R. 1991. Vertebrates associated with tortoise (*Gopherus polyphemus*) burrows in four habitats in south-central Florida. J. of Herpet. 25(4):477–481.

Ludwig, J. A. and J. F. Reynolds. 1988. Statistical ecology: A Primer on Methods and Computing. John Wiley & Sons, New York.

McCoy, E. D. and H. R. Mushinsky. 1992. Studying a species in decline: Gopher tortoises and the dilemma of "correction factors". Herpetologica 48(4): 402–407.

Speake, D. W. 1981. The gopher tortoise burrow community. Pp. 44–47. *In:* Proceedings of the 2nd Annual Meeting of the Gopher Tortoise Council. Florida State Museum, Gainesville, FL.

Velleman, P. F. 1992. Data Desk^4 Statistics Guide. Data Description, Inc. Ithaca, New York, NY.

Witz, B. W., D. S. Wilson and M. D. Palmer. 1991. Distribution of *Gopherus polyphemus* and its symbionts in three burrow categories. Amer. Midl. Natur. 126: 152–158.

Woodruff, R. E. 1982. Arthropods of gopher burrows. Pp. 24–28. *In:* Franz, R. and J. Bryan (eds.). The Gopher Tortoise and its Sandhill Habitat. Proceedings 3rd Annual Meeting Gopher Tortoise Council. Florida State Museum, Gainesville, FL.

Florida Scient. 60(3): 197–201. 1997
Accepted: December 10, 1996.

IDENTIFICATION OF ALLELOPATHIC CHEMICALS IN A POND OF CATTAILS

—*Joaquìn Albalat Domènech* [1], *Eileen Pérez, Maria T. Gallardo, and Dean F. Martin,* Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620-5250

ABSTRACT: *Cattails,* Typha domingensis, *can be a nuisance because of their notable growth in natural waters in Florida. Previous research has indicated that these materials produce substances that are allelopathic, and two chemicals identified in the aqueous extract were 2-chlorophenol and salicylaldehyde. The present study examines sediment samples in a pond infested with cattails, and using gas chromatography the two allelopathic compounds were detected in sediments near, but not 2 m from,* T. domingensis.

CATTAILS, Typha spp. can be troublesome in wetland regions of Florida and other states in the Southeast because of their tendency to proliferate at the expense of other vegetation. Of the ten known species of typha (Pierterse and Murphy, 1993), three thrive in south Florida environments: *T. domingensis, T. latifolia, and T. angustifola,* are the troublesome species (Long and Lakela, 1976).

Previous research (Prindle and Martin, 1996) noted the allelopathic properties of *T. domingensis* in Hillsborough County, Florida. Cattail samples were taken from two locations: a pond on the north edge of the USF Tampa campus and a storm ditch northwest of USF on Bearss Avenue. Allelopathic behavior was demonstrated by taking samples of the plant sections and extracting with water using either an autoclave or a Waring blender; the aqueous extracts were tested using varieties of lettuce seeds. Further research (Prindle et al., 1996) indicated that the extracts contained salicylaldehyde and 2-chlorophenol, based upon GC-MS analysis of the extracts, and it was proposed that the two compounds are responsible, at least in part, for the allelopathic behavior.

The present study was concerned with the occurrence and distribution of these compounds produced in the environment and whether samples of sediment near and some distance from *T. domingensis* would contain either or both of the two allelopathic compounds.

MATERIALS AND METHODS—Samples of salicylaldehyde and 2-chlorophenol were obtained from Fisher Scientific and Aldrich, respectively, and were redistilled before use. A Perkin-Elmer Synch 200 gas chromatograph with a LCI laboratory computing integrator was used with a flame ionization detector (FID). We used a Supelcowax fused silica capillary column (30 m × 0.53 mm with a 1.00 μm film thickness, from Supelco, Inc.) at temperatures of 50–200 °C. Samples of standard solutions in redistilled hexane were injected, and linear results were obtained over the range of 1–100 ppm (area as a function of concentration; $r > 0.9994$). The retention times for salicylaldehyde and 2-chlorophenol were 22.6 and 27.2 minutes, respectively. At a concentration of 1 ppm the relative standard deviation was 1.8 and 3.1% for salicylaldehyde and 2-chlorophenol, respectively.

---

[1] On leave from Universitat de Barcelona, Barcelona, Spain.

Samples of sediment were obtained from a previously studied (Prindle and Martin, 1996) pond that was behind the Police Station on the University of South Florida Tampa campus. Samples of sediment 15 cm in depth were obtained from a previously washed plastic tube which was pushed into the sediment. The samples were returned to the laboratory within minutes in Ziplock plastic bags. Samples were dried at 70°C overnight. Then a known weight of sample was placed into a cellulose thimble and placed in a Soxhlet extractor and extracted with redistilled hexane for 24 hours. Known volumes of the hexane extract were injected into the chromatograph, and the chromatograms were used to identify salicylaldehyde and 2-chlorophenol.

RESULTS AND DISCUSSION—Two groups of samples were obtained: near the cattail infestation and removed from it. The concentration of salicylaldehyde or 2-chlorophenol could not be detected in samples that were more than 2 m from the infestation, which means that they were significantly less than 1 ppm. On the other hand, sediment taken close to the cattails contained 0.0015 and 0.00145% (w/w) in the solid sample (dry-weight basis).

The results, while admittedly limited, do indicate that substances known to be allelopathic toward lettuce seeds have a detectable sediment concentration in the vicinity of cattails, and that the same two substances cannot be detected in sediment samples some distance removed from the cattails. This would imply that the salicylaldehyde and 2-chlorophenol are not uniformly distributed in the sediment of the pond under investigation. The results also indicate that the materials are produced by the cattails, and that it is possible to detect the two allelopathic compounds at a reasonable level and with a reasonable degree of precision.

Given more experience, we anticipate being able to improve on the detection limits and investigate the fate of the allelopathic compounds.

ACKNOWLEDGMENT—We are grateful to Barbara B. Martin for serving as Consulting Editor.

LITERATURE CITED

LONG, R. W. AND O. LAKELA. 1976. A Flora of Tropical Florida. Banyan Books, Miami, FL.

PIERTERSE, A. H. AND K. J. MURPHY (eds). 1993. Aquatic Weeds. Oxford University Press, Oxford.

PRINDLE, V. AND D. F. MARTIN. 1996. Allelopathic properties of cattails, *Typha domingensis,* in Hillsborough County, Florida. Florida Scient. 59: 155–162.

———, W. G. SAWYERS, B. B. MARTIN, AND D. F. MARTIN. 1996. Identification of allelopathic substances from cattails, *Typha domingensis.* Florida Scient. 60 (SP1):24.

Florida Scient. 60(3): 202–203. 1997
Accepted: January 11, 1997.

FLORIDA ACADEMY OF SCIENCES MEDALISTS

1963	Dr. Archie Carr	University of Florida	Biology
1964	Dr. Werner A. Baum	University of Miami	Meteorology
1965	Dr. Alex G. Smith	University of Florida	Astronomy
1966	Dr. Karl Dittmer	Florida State University	Chemistry
1967	Dr. Alfred H. Lawton	University of South Florida	Medicine
1968	Dr. Sidney Fox	University of Miami	Biochemistry
1969	Dr. F. G. Walton Smith	University of Miami	Marine Science
1970	Dr. Pierce Brodkorb	University of Florida	Zoology
1971	Dr. Maurice A. Barton	Mound Park Foundation	Medicine-Teaching
1972	Dr. Lloyd M. Biedler	Florida State University	Physiology-Biophysics
1973	Dr. Ruth S. Breen	Florida State University	Botany
1974	Dr. E. T. York, Jr.	University of Florida	Agriculture
1975	Dr. Alex E. S. Green	University of Florida	Physics
1976	Dr. Robert N. Ginsburg	University of Miami	Geology
1977	Dr. Michael Kasha	Florida State University	Molecular Biophysics
1978	Dr. John Edward Davies	University of Miami	Public Health
1979	Dr. Stanley S. Ballard	University of Florida	Optics
1980	Dr. Thomas D. Carr	University of Florida	Astronomy
1981	Dr. Harold J. Humm	University of South Florida	Marine Biology
1982	Dr. George B. Butler	University of Florida	Chemistry
1983	Dr. Karen Steidinger	Florida Dept. Natural Resources	Biology
1984	Dr. Yngve Ohrne	University of Florida	Chemistry
1985	Dr. William Sears	Florida Atlantic University	Anthropology
1986	Dr. E. Dwight Adams	University of Florida	Physics
1987	Dr. Larry Hench	University of Florida	Engineering
1988	Dr. Gene C. Ness	University of South Florida	Biochemistry
1989	Dr. Frank Bradshaw Wood	University of Florida	Astronomy
1990	Dr. Martin Uman	University of Florida	Electrical Eng'n
1991	Dr. Frank Millero	University of Miami	Oceanography
1992	Dr. Gregory Choppin	Florida State University	Chemistry
1993	Dr. D. O. Shah	University of Florida	Chemical Eng'n
1994	Mrs. Barbara B. Martin	University of South Florida	Chemistry
	Dr. Dean F. Martin	University of South Florida	Chemistry
1995	Dr. James N.Layne	Archbold Biological Station	Zoology
1996	Dr. Leslie Sue Lieberman	University of Florida	Anthropology
1997	Dr. George R. Newkome	University of South Florida	Chemistry

INSTRUCTION TO AUTHORS

Individuals who wish to publish in the *Florida Scientist* must be active members in the Florida Academy of Sciences.

Submit a typewritten original and two copies of the text, illustrations, and tables to the editors. All typewritten material–including the abstract, literature citations, footnotes, tables, and figure legends–shall be double-spaced. Use one side of 8½ × 11 inch (21½ cm × 28 cm) good quality bond paper for the original; the copy may be xeroxed. Margins should be at least 3 cm all around. Number the pages through the Literature Cited section. Avoid footnotes and do not use mimeo, slick, erasable, or ruled paper. Use metric units for all measurements. *Papers in excess of 10 pages by an author in a single volume will result in page charges ($57 per page) for the excess pages.*

Address follows the author's name.

Abstract–all manuscripts shall have a short, concise, single-paragraphed abstract. The abstract follows immediately the author's address.

Acknowledgments are given in the body of the text preceding immediately the Literature Cited section.

Literature Cited section follows the text. Double-space every line and follow the format in the current issue.

Manuscripts of 5 or less, double-spaced typewritten pages should conform to the short article protocol. See recent issue for proper format of both long and short articles.

Tables shall be typed on separate sheets of paper, double-spaced throughout. Each table shall contain a short heading. Do not use vertical rulings. Maximum character width, including spaces, of tables is 98.0. This includes a minimum space of 5 characters between columns.

Illustrations–All drawings shall be done in good quality India ink, on good board or drafting paper. Letter by using a lettering guide or equivalent. Typewritten letters on illustrations are unacceptable. Drawings and photographs should be large enough to allow ⅓ to ½ reduction in size. Photographs shall be glossy prints of good contrast. Whenever possible, mount photographs in lots size.

The author's name and figure number should be penciled lightly on the back of each figure. Figure legends must be listed on a separate page and not on the drawing or photograph. The legend must be double spaced. Illustrations are charged to authors at $16.00 for halftones and $11.00 for line art.

We ask authors to prepare accepted manuscripts in personal computer formats. **Please do not submit a manuscript on disk.** Once reviewers have recommended a manuscript be accepted, you will be given directions for submitting the **final manuscript on disk.**

Proof must be returned promptly. Notification of address change and proofreading are the author's responsibility. Alterations after the type has been set will be charged to the author.

Reprints may be ordered through the Business Manager from the printer on forms provided at the time that proofs are sent to authors for checking.

FLORIDA ACADEMY OF SCIENCES

Institutional Members for 1997

Brevard Community College, Palm Bay
The British Library, Boston Spa, Weatherby, UK
The British Library, RAS Washington DC Professional Campus
Cleveland Public Library, Cleveland, OH
Edison Community College
Florida International University
Harbor Branch Oceanographic Institution, Inc.
Long Island University
St. Petersburg (FL) Junior College
St. Thomas University
St. Thomas University Library
Saint Petersburg Public Library
Science Library, University of Chicago
University of Miami
University of North Carolina at Wilmington

Membership applications, subscriptions, renewals, and changes of address, should be addressed to the Executive Secretary, Florida Academy of Sciences, Orlando Science Center, 777 Princeton St., Orlando, FL 32803

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 University Blvd., Melbourne, FL 32901-6975 [(407) 768-8000, ext. 8196; e-mail rturner@fit.edu]

PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Special bargain: $500 for nearly complete sets. Prices quoted include domestic postage. Some issues may not be available. All are $20 per volume or $5 per issue, except for symposium issues.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES (1936–1944)
  Volumes 1–7
QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCE (1945–1972)
  Volumes 8–35
FLORIDA SCIENTIST (1973–)
Florida's Estuaries—Management or Mismanagement?—Academy Symposium
  FLORIDA SCIENTIST 37(4)–$5.00
Land Spreading of Secondary Effluent—Academy Symposium
  FLORIDA SCIENTIST 38(4)—$5.00
Solar Energy—Academy Symposium
  FLORIDA SCIENTIST 39(3)—$5.00 (includes do-it-yourself instructions)
Anthropology—Academy Symposium
  FLORIDA SCIENTIST 43(3)—$7.50
Shark Biology—Academy Symposium
  FLORIDA SCIENTIST 45(1)—$8.00
Future of the Indian River System—Academy Symposium
  FLORIDA SCIENTIST 46(3/4)—$15.00
Second Indian River Research Symposium—Academy Symposium
  FLORIDA SCIENTIST 53(3)—$15.00

Please send payment with order. If required, an invoice will be sent on purchases over $20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.

ISSN: 0098-4590

F63
H

Florida Scientist

Volume 60 Autumn, 1997 Number 4

CONTENTS

First Documented Nesting by the Green Turtle (*Chelonia mydas*) Along the Southwest Coast of Florida .... Allen M. Foley 205

Comparative Analysis of Growth, Nutrition, Carbon Isotope Ratios, and Hurricane-related Mortality of Slash Pines in South Florida .... Steven F. Oberbauer, Piyal S. Kariyawasam, and James N. Burch 210

Volumetric Exchanges Between a Managed Marsh and a Coastal Estuary .... Ashok Pandit, John H. White, Antonis A. Kakoullis, Satish B. Akula, and James R. David 223

High Breeding Density of Common Moorhens at a Zoological Park .. Brett K. Bannor 236

Behavior of Sea Turtles at an Urban Beach III. Costs and Benefits of Nest Caging as a Management Strategy .... Stephanie L. Adamany, Michael Salmon, and Blair E. Witherington 239

Coastal Currents Induced by Hurricane Andrew .... William McLeish, Donald V. Hansen, and John R. Proni 254

Are Lone Paper Wasp Foundresses Mainly the Result of Sister Mortality? .... Ronald M. Clouse 265

Book Review .... Ernest D. Estevez 275

Book Review .... J. Jasper Lament 277

Awards .... Daryl L. Shrader 279

Acknowledgment of Reviewers 281

Table of Contents, Volume 60 285

SMITHSONIAN
NOV 14 1997
LIBRARIES

FLORIDA SCIENTIST

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Copyright© by the Florida Academy of Sciences, Inc. 1997

Editor: Dr. Dean F. Martin Co-Editor: Mrs. Barbara B. Martin
Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, Florida 33620-5250
Phone: (813) 631-4121; e-mail: Martin@chuma.cas.usf.edu

Business Manager: Dr. Richard L. Turner
Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975
Phone: (407) 768-8000, ext. 8196; e-mail: rturner@fit.edu

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at $40.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

Officers for 1997–1998
FLORIDA ACADEMY OF SCIENCES
Founded 1936

President: Mr. Al Hall
City of Tallahassee
4335 Sherborne Road
Tallahassee, FL 32303

President-Elect: TBA

Secretary: Dr. Richard March
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416

Treasurer: Mrs. Georgina Wharton

Executive Secretary: Ms. Geralyn Heartz
Orlando Science Center
777 East Princeton St.
Orlando, FL 32803
407:896-7151, ext 2079; e-mail: gheartz@osc.org

Program Chairs: Dr. George M. Dooris and Dr. Patricia M. Dooris
Department of Science and Mathematics
St. Leo College
St. Leo, FL 33574

Published by The Florida Academy of Sciences, Inc.
Printing by Allen Press, Lawrence, Kansas

Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Dean F. Martin, *Editor* Barbara B. Martin, *Co-Editor*

Volume 60 Autumn, 1997 Number 4

FIRST DOCUMENTED NESTING BY THE GREEN TURTLE *(CHELONIA MYDAS)* ALONG THE SOUTHWEST COAST OF FLORIDA

Allen M. Foley

Florida Department of Environmental Protection, Florida Marine Research Institute,
100 8th Avenue SE, St. Petersburg, Florida 33701, USA

Abstract: *In 1994, nesting by the green turtle (*Chelonia mydas*) was documented for the first time along the southwest coast of Florida. Twenty-nine nests were recorded in five southwest Florida counties. At least seven to ten turtles were thought to be responsible for this nesting activity. Green turtle nesting was also discovered in three Panhandle counties where it had not been previously reported. Overall, the number of counties in Florida where green turtle nesting had been documented increased during 1994 from 14 to 22. Evidence is presented that green turtles had nested in southwest Florida in 1992 but that these nests had been missed by surveys. One green turtle was tagged and mistakenly identified as a loggerhead while nesting on the southwest coast in 1992. This turtle was subsequently observed nesting on the east coast in 1994, suggesting that the green turtles that nest on the west coast may be a part of the much larger aggregation of turtles that nest on the east coast. The fact that green turtles nest on the southwest coast of Florida shows that this species does indeed nest along low-energy coastlines and shows that nesting surveys may not always detect nesting by rare species.*

Until T. C. Cheatham photographed a green turtle nesting on the east coast of Florida in 1957, there were no substantiated reports of green turtle nesting anywhere on the Florida mainland (Carr and Ingle, 1959). Regular reporting of green turtle nesting activity did not begin until the 1970s, and then only along a 16.7-km beach (Hutchinson Island, Martin County) (Dodd, 1982).

In 1979, the Florida Department of Environmental Protection (then the Department of Natural Resources) began compiling data on the statewide nesting activity of marine turtles. These data were collected primarily during early-morning surveys by various entities (private citizens, governmental agency personnel, members of conservation organizations, university researchers, etc.). During the next 15 years, green turtle nesting activity was

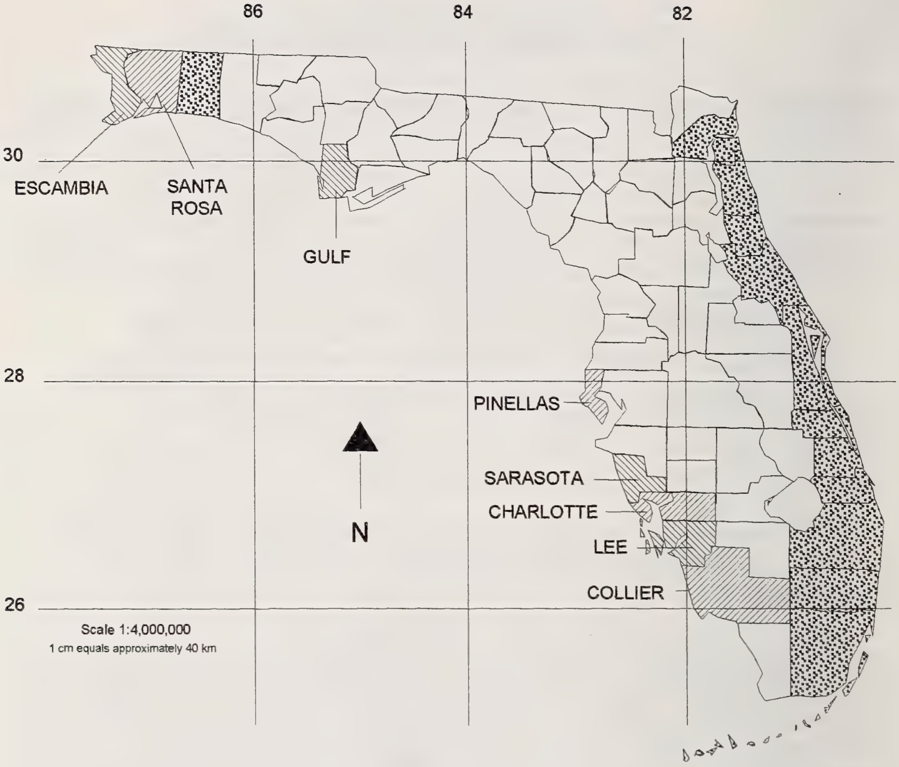


FIG. 1. Florida counties where green turtle (*Chelonia mydas*) nesting activity has been documented. Shaded areas represent counties where nesting activity had been documented prior to 1994. Cross-hatched areas represent additional counties where 35 green turtle nests were observed in 1994.

regularly documented along most of the east coast and in a few areas along the northwest coast (the "Panhandle"). Despite extensive surveys, however, no such activity was ever reported along the southwest coast (Conley and Hoffman, 1987; Meylan et al., 1995). This paper reports on the 1994 nesting season, during which green turtle nests were documented for the first time in southwest Florida.

During 1994, 29 green turtle nests were discovered in five southwest Florida counties (Pinellas, Sarasota, Charlotte, Lee, and Collier; Table 1, Fig. 1). Assuming a renesting interval of no less than ten days (Johnson, 1994), and a clutch frequency of three (Johnson and Ehrhart, 1996), at least seven to ten individuals are believed to have nested in southwest Florida in 1994.

During that same year, six green turtle nests were reported in three Panhandle counties where nesting had not been previously known (Escambia, Santa Rosa, and Gulf; Fig. 1). Prior to 1994, green turtle nesting had

TABLE 1. Records of 1994 green turtle (*Chelonia mydas*) nesting activity in five counties along Florida's southwest coast where green turtle nesting had not been previously documented. The data are based on daily nesting surveys except in the Ten Thousand Islands (Collier County), which was surveyed once or twice a week. The author confirmed the species identification of hatchlings or embryos from 15 nests and the track and/or nest site characteristics from the other 14 nests.

County	Location	Date discovered
Pinellas	Ft. Desoto Park, SW Mullet Key, 27°37.3′N, 82°44.3′W	August 3
Sarasota	Casey Key (central), 27°08.0′N 82°28.4′W	June 6
	Casey Key (central), 27°08.5′N 82°28.5′W	June 22
	Venice, Horse and Chaise Point, 27°03.8′N 82°26.8′W	July 24
	Manasota Key, Casperson Beach, 27°02.8′N 82°26.2′W	June 7
	Manasota Key, Blind Pass Beach, 26°58.0′N 82°23.3′W	July 6
Charlotte	Manasota Key, Englewood Beach, 26°56.1′N 82°22.1′W	June 17
	Manasota Key, Englewood Beach, 26°55.9′N 82°22.0′W	July 14
	Don Pedro Island, north of state park, 26°51.0′N 82°18.4′W	June 9
	Don Pedro Island, in state park, 26°50.4′N 82°17.9′W	June 22
	Don Pedro Island, north of state park, 26°51.0′N 82°18.4′W	July 1
	Don Pedro Island, north of state park, 26°51.0′N 82°18.4′W	July 12
	Don Pedro Island, in state park, 26°50.9′N 82°18.3′W	July 24
	Don Pedro Island, north of state park, 26°51.0′N 82°18.4′W	July 31
	Don Pedro Island, north of state park, 26°51.5′N 82°18.7′W	August 4
	Don Pedro Island, north of state park, 26°51.4′N 82°18.6′W	August 11
Lee	Gasparilla Island, Boca Grande, 26°44.7′N 82°15.8′W	June 24
	Gasparilla Island, Boca Grande, 26°44.0′N 82°15.8′W	July 5
	Gasparilla Island, Boca Grande, 26°44.7′N 82°15.8′W	July 23
	Gasparilla Island, Boca Grande, 26°44.0′N 82°15.8′W	August 5
Collier	Naples Public Beach, 25 Ave. South, 26°07.1′N 81°48.3′W	July 3
	Keywadin Island, south end, 26°0.9′N 81°46.0′W	July 8
	Ten Thousand Islands, Turtle Key, 25°52.8′N 81°35.5′W	*

* A green turtle nest was discovered in the same area of Turtle Key on each of the following days: June 29; July 6, 13, and 27; and August 5, 18 and 24.

been documented in 14 Florida counties. Eight more counties were added to this list during 1994, bringing the number of counties where green turtle nesting is known to occur to 22 (Fig. 1).

Evidence was also discovered during 1994 that green turtles had nested on the southwest coast of Florida in 1992 but had not been documented during surveys. A nesting green turtle was tagged on Manasota Key (Sarasota County) in 1992 but was incorrectly identified as a loggerhead (*Caretta caretta*). The tracks and nest site were also identified as those of a loggerhead during the next morning's survey. In 1994, researchers from the University of Central Florida encountered the same turtle while it was nesting on Melbourne Beach (Brevard County, east coast) and positively identified it as a green turtle (D. Bagley, 1994). Additionally, nesting-survey personnel from Charlotte County and Pinellas County showed the author photographs taken in 1992 of what were probably green turtle tracks that had been misidentified as loggerhead tracks.

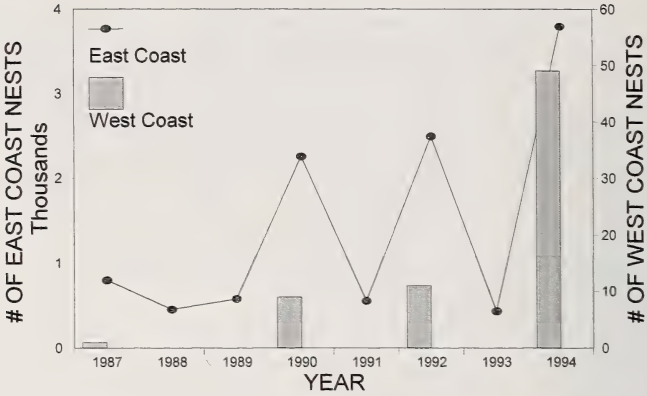


FIG. 2. Numbers of green turtle (*Chelonia mydas*) nests documented in Florida from 1987 to 1994. The data include numbers of nests on the east coast (including Monroe County) and numbers of nests on the west coast. Data Source: Florida Department of Environmental Protection, Florida Marine Research Institute, Florida Marine Turtle Nesting Summary Database, Data Summary Date: 30 November 1995.

Nesting by an individual green turtle on both coasts suggests the possibility that the green turtles that nest along the west coast of Florida may be part of the larger aggregation that nests on the east coast. This view is further supported by the corresponding yearly fluctuations in the number of green turtle nests along both coasts. Green turtle nests on the west coast have been documented only during 1987, 1990, 1992, and 1994 (only in northwest Florida prior to 1994). These were also the years when the number of green turtle nests peaked on the east coast (Fig. 2).

The similarity of yearly fluctuations in the number of green turtle nests along both coasts of Florida may also be attributed to corresponding ecological events on feeding grounds. There may be two (or more) distinct nesting populations in Florida that may be responding to the same environmental conditions either because they share feeding grounds or because their separate feeding grounds experience similar climatic variations (Limpus and Nicholls, 1988).

Green turtle nesting beaches are typically located along high-energy shores. Carr and co-workers (1974) attributed this to the species' preference for deep-sand beaches. In Florida, Tanner (1960) classified the beaches on the east coast from Volusia County to Dade County as high-energy (annual mean breaker height >50 cm). This is also where most (>98%) green turtle nesting takes place in Florida. Nevertheless, green turtle nesting does occur on lower-energy coastlines. On the west coast of Florida, green turtles have nested on beaches of both moderate energy (annual mean breaker height >10 cm but <50 cm; Tanner, 1960) and low energy (annual mean breaker height <10 cm; Tanner, 1960). Seven nests were found by the author in 1994 on the low-energy beach of a small, low-relief mangrove island in Collier County (Turtle Key, Ten Thousand Islands; see Table 1).

The documentation of nesting by endangered green turtles along the southwest coast of Florida heightens the importance of these beaches in management considerations, especially if nesting in this area increases or continues on a regular basis. As on other beaches in Florida, much of the nesting habitat along the southwest coast has been degraded or is threatened by human-related changes such as coastal armoring, beach nourishment, beachfront development, and beachfront lighting (Meylan et al., 1995).

The recent discovery of nesting by green turtles in southwest Florida also provides two useful lessons for researchers and natural resource managers working on other beaches. The first is that green turtle nesting may occur along moderate- or low-energy shores. The second is that even extensive surveys may fail to detect a small amount of nesting by one species because of errors in track and nest-site identification.

ACKNOWLEDGMENTS—Data on green turtle nesting activity along Florida's west coast were collected primarily by J. Foote, J. McCarthy, B. Starr, A. Samply, D. Addison, C. Ramsey, L. Hose, B. Browning, D. Atencio, R. Hoggard, G. Gray, and B. Eels. Many others who were associated with those listed above also deserve credit for helping to conduct the nesting surveys that led to the discovery of green turtle nests. Credit should also be given to A. Huff, C. Futch, and R. Witham for initiating the statewide nesting survey program and to W. Conley, B. Hoffman, B. Schroeder, A. Meylan, and A. Mosier for editing, compiling, and entering nesting data.

This paper benefitted greatly from reviews by A. Meylan, B. Schroeder, and J. Leiby. I would also like to thank A. Mosier for providing the map in Fig. 1.

Funding for this study was provided in part through grant number NG92-100 from the Nongame Wildlife Program of the Florida Game and Freshwater Fish Commission.

LITERATURE CITED

BAGLEY, D. 1994. Univ. Central Florida, Orlando, Pers. Commun.

CARR, A. F. AND R. M. INGLE. 1959. The green turtle (*Chelonia mydas*) in Florida. Bull. Mar. Sci. Gulf Caribb. 9(3):315–320.

———, P. ROSS, AND S. CARR. 1974. Internesting behavior of the green turtle, *Chelonia mydas*, at a mid-oceanic island breeding ground. Copeia 1974:703–706.

CONLEY, W. J. AND B. A. HOFFMAN. 1987. Nesting activity of sea turtles in Florida, 1979–1985. Florida Scient. 50:201–210.

DODD, C. K. 1982. Nesting of the green turtle, *Chelonia mydas* (L.), in Florida: historic review and present trends. Brimleyana (7):39–54.

JOHNSON, S. A. 1994. Reproductive ecology of the Florida green turtle (*Chelonia mydas*). Unpubl. M.S. Thesis, Univ. Central Florida, Orlando, 108 pp.

JOHNSON, S. A. AND L. M. EHRHART. 1996. Reproductive ecology of the Florida green turtle: clutch frequency. J. Herp. 30(3):407–410.

LIMPUS, C. J. AND N. NICHOLLS. 1988. The southern oscillation regulates the annual numbers of green turtles (*Chelonia mydas*) breeding around Northern Australia. Aust. J. Wildl. Res. 15:157–161.

MEYLAN, A., B. SCHROEDER, AND A. MOSIER. 1995. Sea turtle nesting activity in the State of Florida 1979–1992. Fla. Mar. Res. Publ. No. 52:1–51.

TANNER, W. F. 1960. Florida coastal classification. Gulf Coast Assoc. Geol. Soc Trans., X:259–266.

Florida Scient. 60(4): 205–209. 1997
Accepted: March 4, 1997.

COMPARATIVE ANALYSIS OF GROWTH, NUTRITION, CARBON ISOTOPE RATIOS, AND HURRICANE-RELATED MORTALITY OF SLASH PINES IN SOUTH FLORIDA

Steven F. Oberbauer(1,2), Piyal S. Kariyawasam(1), and
James N. Burch(1)

(1)Department of Biological Sciences, Florida International University, Miami, FL 33199 and
(2)Fairchild Tropical Garden, 11805 Old Cutler Road, Miami FL 33156

Abstract: *Slash Pines (*Pinus elliottii *var.* densa*) were studied in sites within and outside of Everglades National Park (ENP) to determine if high mortality (80–99%) in sites out of ENP following Hurricane Andrew could be related to tree water status, nutrient status, or growth rate. Tree ring chronologies and carbon isotope measurements were used to compare growth rates and water stress levels from recent and old wood. Needle N, P, and C and their ratios were used to compare the nutrient status of surviving trees. Contrary to expectations, carbon isotope ratios of recent wood from trees in ENP indicate water stress levels similar to and in some cases higher than water stress levels of pines outside of ENP. Similarly, leaf nutrients and basal area increments were relatively low in the ENP stands compared to those of Dade County sites outside of ENP. Basal area increments of recent wood were positively correlated with $\delta^{13}C$ and leaf N and P, suggesting that growth is limited by water and nutrient stress at some of the sites. Furthermore, isotope ratios from most of the sites, including those within Everglades National Park, imply that water stress may have increased relative to 25–35 years ago. While the results do not provide the basis for explaining widespread pine mortality outside of ENP, they indicate that in some sites, water stress and nutrients may limit regrowth of these stands.*

The Miami Rock Ridge uplands in subtropical southern Florida were once dominated by pine rocklands, a unique and diverse fire-maintained community. These habitats are characterized by an open overstory of South Florida Slash Pine, *Pinus elliottii* var. *densa* Little & Dorman. The heterogeneous understory consists of palms, shrubs, and herbaceous perennials growing on exposed oolitic limestone or sand. The diverse flora includes a large number of endemic and several threatened or endangered plant species (Ward, 1979; Loope and Avery, 1979; Snyder et al., 1990). The area of pine rocklands has been severely reduced due to logging and urban and agricultural development. Outside of Everglades National Park, pine rocklands exist on only about 3% of their former extent (O'Brien, 1996) and are currently ranked as a globally imperiled community by the Florida Natural Areas Inventory. Many of the remaining pinelands consist of small, isolated tracts; the largest extant tract is in Everglades National Park (ENP) on Long Pine Key.

Pine rocklands are a disturbance-driven community. Historically maintained by lightning-strike fires, in the absence of fire, pinelands succeed to tropical hardwood hammocks (Robertson, 1955). Hurricanes also regularly disturb pinelands. In the past century, however, an additional disturbance regime has been imposed by urbanization in the area. Between 1920 and 1965, canal construction and water diversion throughout much of the region have lowered the water table (Gunderson et al., 1995), an important source of water for slash pines (Ross et al., 1994). Fire suppression and fragmentation of the stands have led to altered fire regimes. Furthermore, many of the remaining pinelands have been invaded by exotic plant species, particularly Brazilian Pepper (*Schinus terenbinthefolia* Raddi) and Burma Reed (*Neyraudia reynaudiana* (Kunth) Keng). Perhaps not coincidentally, many of the pines outside of ENP have been in decline.

In August 1992, Hurricane Andrew impacted most of the remaining pinelands (Loope et al., 1994; Armentano et al., 1995). Though some trees were killed directly by the hurricane, an insect outbreak in 1993 resulted in nearly 100% post-storm mortality in several of the sites outside of ENP (Armentano et al., 1995). In marked contrast, pines in ENP sustained relatively low post-storm mortality. The direct agents of mortality were native species of bark beetles and weevils and the fungal pathogens that they carry, but why pines in some sites were less affected has not been determined.

The sites within ENP differ from those outside of ENP in several significant ways. Although the hydrology of the entire region has been affected by canal construction, water management in the region is mandated to deliver water to ENP. In contrast, areas outside ENP have been dissected by a network of flood control canals. Consequently, Everglade pinelands might be expected to have a more favorable water status than the other sites. Likewise pinelands in ENP have been under a fire management regime since the late 1950s; since 1981, the fire management has been designed to mimic the natural seasonal pattern of burning (Doren et al., 1993). Pinelands outside of ENP, on the other hand, have not been fire-managed for the most part and in many cases have been invaded by exotic plants. The slow turnover of nutrients in biomass and litter due to long fire intervals and the competition for nutrients by exotic plants should lower the nutrient status of pines outside of ENP relative to that of pines in the Everglades.

The objective of this study was to test the hypothesis that growth of slash pines in southern Florida is limited by water and/or nutrient stress, and that a synergism between hurricane damage and these stresses triggered the susceptibility of pines to insect attack in some sites. Higher growth rates should indicate lower stress and better ability to survive insect or pathogen attack, or a lower attractiveness to insects (Tisdale and Wagner, 1991).

To address these issues, we measured carbon isotope ratios of wood, tree ring width, and leaf nutrients from pinelands in sites with high and low post-storm mortality. We used carbon isotope ratios to infer site water status both recent and past (McNulty and Swank, 1995) and tree rings were used

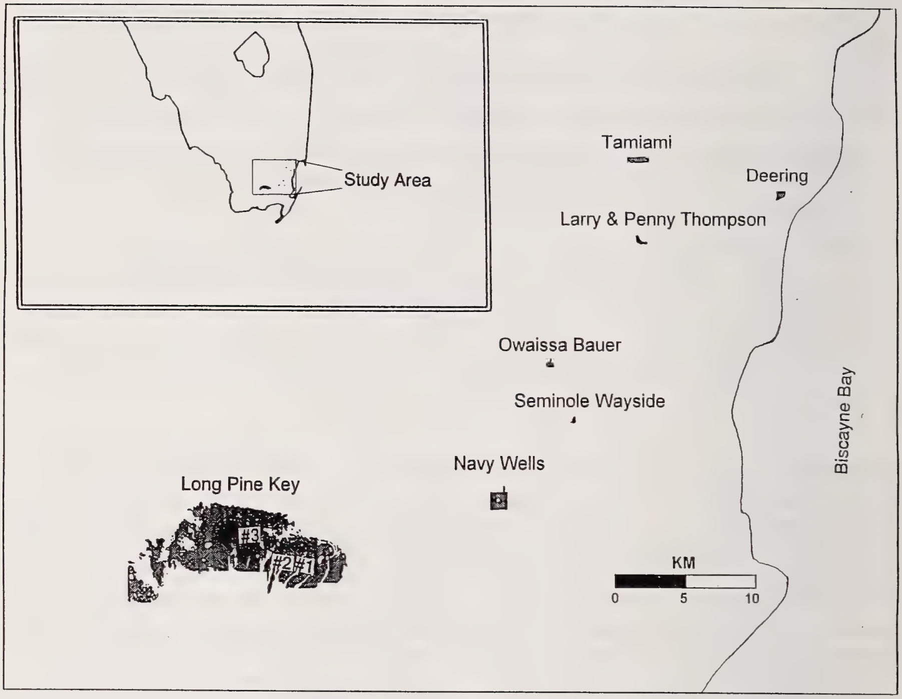


FIG. 1. Locations and relative sizes of study sites.

to assess growth for the corresponding periods. Leaf nitrogen, phosphorus, and carbon levels and their ratios were used to evaluate N and P limitation at the study sites. The ratios of C:N and C:P are particularly useful as indicators of nutrient limitation (Atkinson and Smith, 1983) and are typically better indicators than the simple elemental content on a dry weight basis. Plants in sites of low nutrient availability tend to have higher proportions of C relative to N and P.

METHODS—*Study sites*—Nine sites were compared comprising three within and six outside of Everglades National Park (Fig. 1, Table 1). The three Everglades sites are located in Long Pine Key. All three sites are low elevation sites (0–1.5 m) on rocky oolitic limestone soils. Everglades pinelands were logged between 1935 and 1947 (Snyder et al., 1990) and most of the sample trees date to the 1940's. Consequently, the stands are relatively even aged with relatively open canopies (Doren et al., 1993). All three sites incurred some damage (22% mortality overall, Oberbauer et al., unpublished data) during Hurricane Andrew, but relatively low post-hurricane mortality occurred within these stands.

The sites outside of ENP range in size, soil, and elevation (Fig. 1, Table 1). The three southern sites are on oolitic limestone soils, while the more northern sites have sandy soils. Two of the sites, Deering Estate and Camp Owaissa Bauer, are at somewhat higher elevations (3–6 m) than the other sites (0–3 m). Navy Wells is the site of a large municipal well field. The logging histories of Dade County Parks are largely undocumented, but most sites were cut between 1896 and 1946 (Snyder et al., 1990), and most stands are of similar age and openness

TABLE 1. Characteristics of the study sites used in this project. Pine mortality includes post-storm mortality caused by insect attack.

Location	Soils	Elevation m	Pine mortality %
Everglades National Park—Long Pine Key			
Pineland 1	oolitic limestone	0–1.5	55
Pineland 2	oolitic limestone	0–1.5	23
Pineland 3	oolitic limestone	0–1.5	15
Dade County			
Navy Wells	oolitic limestone	1.5–3	>95
Seminole Wayside Park	oolitic limestone	1.5–3	>80
Camp Owaissa Bauer	oolitic limestone	4.5–6	>90
Larry and Penny Thompson Park	sand	1.5–3	>99
Tamiami Pineland	sand	1.5–3	>99
Deering Estate	sand	3–4.5	>90

to those in ENP. Mortality of pines following the insect outbreak was very high in all of the sites outside of ENP (Table 1, McHargue, 1994.). Larry and Penny Thompson Park had virtually 100 % mortality with few seedlings or saplings regenerating.

All of the study sites fell within the track of the eye of Hurricane Andrew and experienced the full impact of the hurricane-force winds (Armentano et al., 1995). Peak winds of the leading (west) and trailing (east) eyewalls of the hurricane were apparently comparable to those of the right (north) eyewall of the hurricane (Armentano et al., 1995). The three ENP sites and the three southernmost Dade County Parks were south of the center of the hurricane eye (Fig. 1). The other three Dade County Parks were within the northern eyewall of the hurricane (Armentano et al., 1995).

Isotope analysis—Because live trees were scarce or absent, we sampled only hurricane-killed trees in the Dade County sites. We used trunk sections from snapped-off or tipped-up trees as the source of wood tissue. By using hurricane-killed trees, we could be sure of the age of the tree for establishing the growth chronology. Trunk sections were taken with a chainsaw from a position approximating breast height when possible to minimize effects of tree height on $\delta^{13}C$. For isotope sampling, a 5 mm drill bit was used to extract recent (5–10 years before Hurricane Andrew) and old (25–35 years earlier) wood tissue from the sections. Wood from several years growth was sampled to moderate the influence of any single year. Several radii on each section were sampled to average variation around the trunk. Care was taken to avoid areas with fungal decomposition. Seven trees from each site were analyzed for carbon isotopic composition.

For the ENP sites, we sampled wood of live trees near breast height with an increment borer. Two cores were taken per tree with cores spanning the tree to provide four samples. Wood samples were dried at 70°C and ground with a Wiley Mill. Samples were analyzed by mass spectrometer (Ehleringer and Osmond, 1989) without any further extraction by Metabolic Solutions, Inc., Merrimac, NH, USA. Data are presented in terms of $\delta^{13}C$ in parts per thousand of the sample relative to the Pee Dee belemnite limestone standard. A more negative value of $\delta^{13}C$ (lighter sample) indicates higher discrimination against $^{13}CO_2$ relative to $^{12}CO_2$ and therefore lower water stress (Rundel et al., 1988).

Tree ring analysis—Tree ring chronologies of the cores and stem sections sampled for $\delta^{13}C$ were measured to compare growth among sites and changes in growth with time. Stem cores were hand sanded before measurement. Stem sections were smoothed using a router and then hand sanded. The growth increments of each sample were measured for three radii at five-year cumulative widths using a dissecting microscope and an ocular micrometer. We measured five-year cumulative widths to minimize any effects of false rings (Ewel and Parendes, 1984), which are sometimes evident in these trees. To correct for the allometric effect of tree diameter on ring width, growth increment was converted to basal area increment (BAI) for statistical comparisons by assuming the stems were circular and using the mean diameter increment to calculate the areal increase.

Leaf nutrients—Canopy needles were collected in December 1994 or January 1995 using a slingshot or tree pole. For each tree a small canopy level branch was collected and subsamples of fascicles taken from those for tissue analysis. Ten trees were sampled for leaves at each site except for ENP P2 for which only nine trees were sampled. Needles were dried for 48 hrs or more at 70 °C and then ground with a Wiley mill. Samples were analyzed for carbon and nitrogen using an Carlo Erba elemental analyzer. Total phosphorus was analyzed with an Alpkem Rapid Flow Analyzer using standard techniques. Leaves were not collected from Tamiami Pineland, Larry and Penny Thompson, or Deering Estate because sufficient living tissue was not available for sampling.

Data analysis—For comparisons among means of $\delta^{13}C$ for recent and old wood, a paired-T test was used after testing the data for normality. For comparisons of $\delta^{13}C$ among sites, a one-way ANOVA was used after testing for normality and heterogeneity of variances. Tukey's HSD was used for pairwise comparisons among means. Growth rates over 5 and 20 year intervals were compared using Kruskall-Wallis non parametric one-way ANOVA. Leaf nutrients were also analyzed using non parametric one-way ANOVA. Relationships between growth, isotope ratios, and leaf nutrients were tested using Pearson correlations. Data were analyzed using the microcomputer statistical package, STATISTIX 4.1 (Analytical Software, Tallahassee FL, USA).

RESULTS—*Isotope analysis—site comparison*—Isotope ratios of recent wood from among the sites differed significantly, but not in the expected pattern of more negative $\delta^{13}C$ (less water stress) for ENP sites (Fig. 2). For recent tissue, the greatest discrimination (lowest $\delta^{13}C$) was found for Tamiami Pineland and Seminole Wayside Parks (Fig. 2). $\delta^{13}C$ of the three ENP sites were intermediate and those of Owaissa Bauer and Deering Estate were highest. For old tissue, the sites did not statistically differ (Fig. 2), but the highest discrimination was found for Pineland 1 in ENP, followed by those of Seminole Wayside and Tamiami Pineland. The lowest discrimination was found for Camp Owaissa Bauer and Larry and Penny Thompson. The greatest within-site variation in isotope ratio occurred at Camp Owaissa Bauer and Deering Estate for recent tissue, and at Seminole Wayside and Deering Estate for old tissue (Fig. 2).

Isotope analysis—recent versus old comparison—Most sites showed lower discrimination of $\delta^{13}C$ in recent tissue than in old tissue. The one exception was Tamiami Pineland, a sandy site with high discrimination overall. For many sites the differences were statistically significant (Fig. 2). When sites within ENP combined were compared with Dade County sites for the change in $\delta^{13}C$ from old to recent tissue, the differences were not significant. The difference between recent and old tissue was greatest for tissue from the Deering Estate. Isotope ratios for recent and old wood of

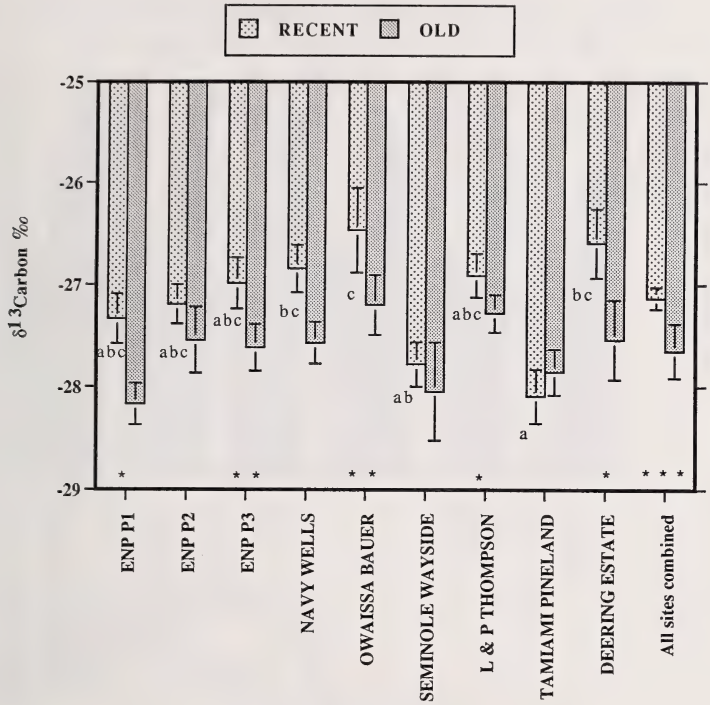


FIG. 2. Mean δ^{13}C (‰) from recent and old wood from three sites within Everglades National Park and six sites in Dade County Parks. Asterisks indicate that recent and old wood were significantly different; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. Sites with different letters (recent wood) indicate significant differences at $P < 0.05$. There were no significant differences for old wood.

individual trees were significantly correlated; past δ^{13}C explained 37% of the variation in recent δ^{13}C.

Leaf nutrients—The pattern of leaf nutrients and their ratios were not consistent with the idea that trees in ENP have a more favorable nutrient status (Fig. 3). Leaf N and P were highest for two of the sites outside of ENP, Seminole Wayside and Navy Wells. These sites were significantly higher in terms of P and N than the ENP sites and Owaissa Bauer. The low values of N and P of leaves from Owaissa Bauer and the ENP sites were accompanied by high C:N and C:P ratios suggesting that N and P were more limiting at these sites (Table 2).

Growth rates—The tree ring analysis revealed that the growth rates in Everglade pinelands were lower than those in most of the Dade County sites (Fig. 4). Statistical analyses of recent BAI (1985–1989) indicate that the growth rates have been relatively similar among the sites except for those

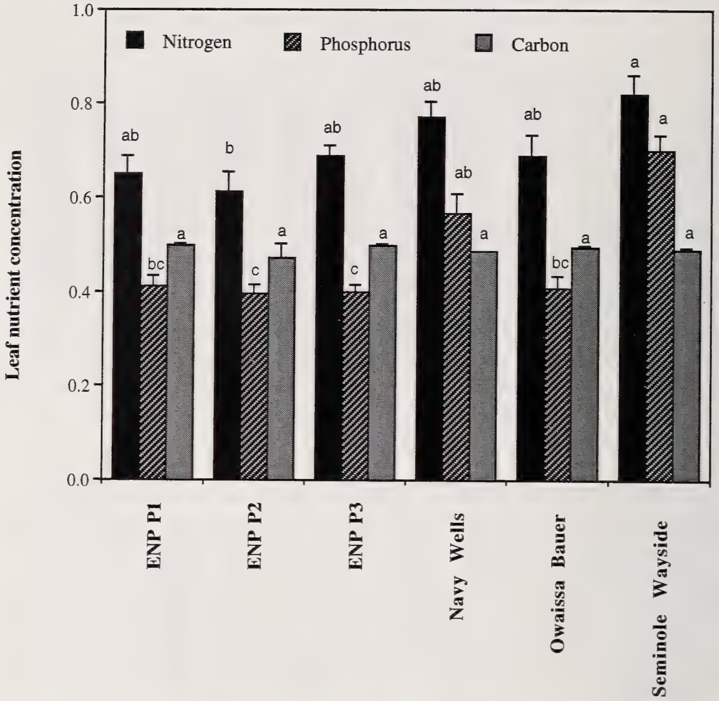


FIG. 3. Needle nitrogen, phosphorus, and carbon concentrations of slash pines from six sites in southern Florida. Concentrations are nitrogen (% dry weight), phosphorus (mg g^{-1} dry weight) and carbon (g g^{-1} dry weight) Values are means ± SE (n = 9 or 10).

at Tamiami Pineland (Table 3), which were higher. When the total growth is compared over the twenty year period ending in 1989, the sites fall into two mostly overlapping groups. In general, the sites in the Everglades and the Deering Estate had the lowest growth rates. Although stand ages differ in some cases, age differences are probably not sufficient to account for the results. Variability within the sites was fairly large and greater in the sites outside of ENP (Fig. 4). For most sites, BAI was higher at some time in the past relative to recent BAI.

TABLE 2. Elemental ratios of leaf nutrients for carbon, nitrogen and phosphorus from six of the study sites.

Site	C:N	C:P	P:N
ENP P1	79.4 ab*	1241 ab	0.064 ab
ENP P2	71.2 a	1226 ab	0.064 ab
ENP P3	73.1 abc	1253 a	0.059 b
Navy Wells	64.7 bc	887 bc	0.075 ab
Owaissa Bauer	75.3 abc	1255 ab	0.060 b
Seminole Wayside	61.1 c	718 c	0.086 a

* Different letters within a column indicate values are different at $P < 0.05$.

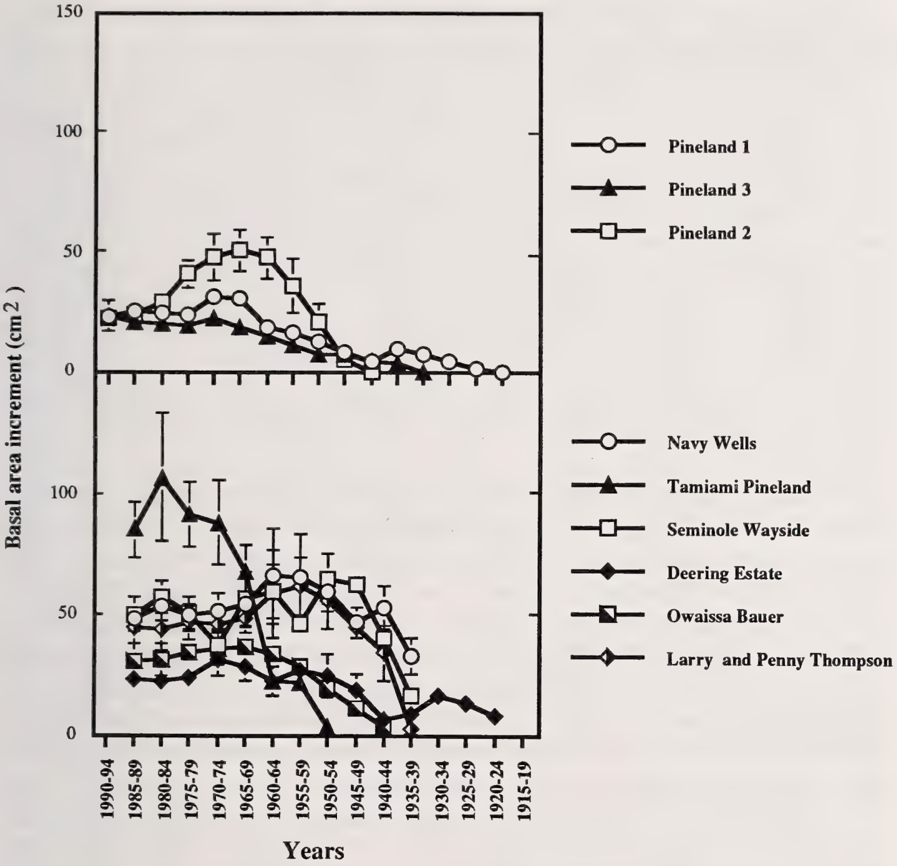


FIG. 4. Average basal area increments (cm^2) for slash pine in and outside of Everglades National Park. Values are means ± SE of 5 year BAI increments (n = 5 or 6). In some sites for older time periods, lines may represent fewer than 5 trees if some trees were substantially older than most.

Correlations between isotope ratio, growth and nutrients—Recent basal area increments were significantly correlated with recent wood $\delta^{13}C$ (Table 4) suggesting that growth in slash pine is limited by water stress. It should be noted that the correlation is strongly leveraged by the data from Tamiami Pineland. Recent growth, however, showed no relationship to old wood isotope ratio. Growth over the interval 1985–1989 was strongly correlated with growth in the previous five years and even with growth over the period from 1970 to 1979.

Growth during the periods 1980–84 and 1985–1989 was also significantly correlated with leaf N and P for the sites for which we had data (Table 4). Carbon isotope ratios were not significantly correlated with any of the measured leaf elements.

TABLE 3. Results of Kruskal Wallis nonparametric one-way ANOVA for basal area increments of the nine study sites using the growth periods 1985–1989, 1980–1984, and 1970–1989.

Site	Basal area increment (cm^2)		
	1985–1989	1980–1984	1970–1989
Tamiami Pineland	84.4 a*	105.7 a	367.9 a
Navy Wells	47.8 ab	53.1 ab	200.4 ab
Seminole Wayside	49.3 ab	56.6 ab	191.9 ab
Larry & Penny Thompson	43.6 ab	43.2 ab	178.2 ab
Owaissa Bauer	29.6 ab	30.5 ab	128.3 ab
ENP Pineland 1	25.4 ab	24.4 ab	104.9 b
ENP Pineland 2	23.5 ab	28.9 ab	140.4 ab
Deering Estate	22.4 b	21.8 b	98.0 b
ENP Pineland 3	20.6 b	20.4 b	82.7 b

* Means in a column followed by the same letter are not significantly different at $P < 0.05$ (n = 5 or 6).

DISCUSSION—The results of this study do not support the hypothesis that pinelands in the Everglades are at a more favorable water or nutrient status than pinelands outside of ENP. Contrary to our expectations, pines in ENP are currently intermediate in terms of water and nutrient status. The results do, however, support the idea that water and nutrient stress limits the growth of slash pines in southern Florida. Trees with the lowest growth rates were enriched for ^{13}C (more water stress) and had higher C:N and C:P ratios. Furthermore, trees on the two sites with the highest elevations, Camp Owaissa Bauer and Deering Estate, had among the lowest growth rates and highest water stress. We had anticipated higher growth rates of pines in ENP as a result of better hydrology and fire management. Trees with high growth rates should be less susceptible to insect attack (Tisdale and Wagner, 1991). Instead, we found relatively low growth rates in the ENP stands.

Furthermore, the data suggest that the water status of these slash pines has recently declined, consistent with the general lowering of water tables in the region (Gunderson et al., 1995). The ENP sites and most of the Dade

TABLE 4. Pearson correlation coefficients between site mean recent and old wood isotope ratios, leaf nutrients, and basal area increment during recent five and ten year periods.

Site	Basal area increment	
	1980–1984	1985–1989
$\delta^{13}C$-recent	0.72*	0.68*
$\delta^{13}C$-old	0.22	0.18
BAI 1985–1989	0.99*	—
BAI 1970–1979	0.96*	0.94*
Leaf nitrogen	0.87*	0.90*
Leaf phosphorus	0.94*	0.94*
Leaf carbon	−0.24	−0.10

* Indicates correlation is significant at $P < 0.05$. n = 10 for growth and isotope correlations and n = 6 for correlations with nutrients.

County Parks showed a lower isotope discrimination in recent growth compared to older wood. In agreement with this finding, most sites showed a decline in recent growth. This finding could be a result of the severe drought in late 1980's, but tissue sampling for isotope and growth reductions both extend beyond those years.

Isotope ratios for slash pines in this study are similar to those reported for Sugarloaf Key (Ross et al., 1994) but indicate higher water status on mainland pines than for those in Sugarloaf. In core pine forest on Sugarloaf, they found $\delta^{13}C$ of -25.5 ‰ but in peripheral pine forest declining due to rising sea level, they found $\delta^{13}C$ of -23.8 ‰. Values from the present study ranged from -28.09 to -26.59 ‰, a wider range than McNulty and Swank (1995) found for white pine over a period when soil water potentials averaged from greater than -1 MPa to -5.5 MPa.

Post-hurricane mortality rates of trees in Dade County Parks were very high, but precise quantitative data are not available. However, pine mortality is apparently not strongly related to isotope ratio, therefore pine water status at the stand level. The sites within ENP for which we have quantitative data also do not follow the expected pattern of lower mortality (total and post-storm) with more water stress. Growth rates also did not correspond closely to mortality, as both sites with high average growth rates and sites with low average growth rates had high mortality. This conclusion does not preclude the possibility that within a stand, water-stressed trees had a higher probability of dying. Some sites had relatively high tree to tree variation. Also, we examined general patterns of growth and isotope ratio in a time frame of several years, but the water status in each site at the time of Andrew or shortly thereafter may have contributed to mortality patterns while not being detected in this analysis. However, how such differences would arise is not clear, particularly considering the very strong correlation between growth over the 5-year intervals. Also, rainfall in the region in 1992–1993 was above average.

Factors other than water stress can affect $\delta^{13}C$, although water stress is frequently the most important. Isotope ratios may reflect differences in stand structure and therefore light environment and competition for water. Typically, however, under higher light environments, $\delta^{13}C$ declines, contrary to the results presented here for the recent versus old comparison. Furthermore, all of the sites had open stands of relatively similar age. Recycling of soil respiratory CO_2 is known to influence $\delta^{13}C$ of wood in closed forests (Broadmeadow and Griffiths, 1993), but the amount of litter available for decomposition is very low and the stands are relatively open, making unlikely that high concentrations of respiratory CO_2 accumulate for photosynthetic uptake. Both atmospheric CO_2 concentration and $\delta^{13}C$ changed over the time interval from old to recent tissue, but the direction of the effects should be opposite to the direction of recent versus old differences. One additional possibility is that flooding induced physiological drought of the ENP trees resulting in heavier signatures for those trees. Langdon (1963) suggested that high water tables may reduce growth of *P. elliottii* var *densa*. However, flooding effects should have been greater for older tissue which was produced when water tables were higher. Instead we see less stress in the older tissue. Ozone stress has also been reported to affect isotope signatures at high concentrations (Elsik et al., 1993). Nevertheless, despite these potential artifacts, the isotope data are consistent with pine growth, elevational differences, and hydrological changes suggesting that they are indeed reflecting water status.

The finding of higher leaf N and P levels in pines outside of ENP was unexpected and the basis for such differences is not clear. Differences in soil parent material are one possibility. Although all the sites are on the same geologic formation, some soil differences exist (O'Brien, 1996). Higher phosphorus may also have resulted from groundwater contamination. Nitrogen deposition from air pollution is one possibility but the subject needs further investigation. The correlation between past site growth rates and leaf nutrients discounts the possibility that such difference arose post-hurricane as a result of nutrient release from hurricane-killed trees.

The question remains, what factor(s) triggered susceptibility in so many trees in Dade County Parks? Possibilities include damage due to variation in wind speeds, reduced overall tree vigor due to factors such as competition from exotics, fire regime and stand history, air pollution, site geology, and chance conditions favorable to insect outbreak dynamics.

Wind speeds during the hurricane may have differentially damaged surviving trees in these stands, ultimately leading to susceptibility to insect attack. Armentano and co-workers (1995) report that the number of severely damaged trees was far greater in Navy Wells and Deering Estate than in Long Pine Key. They attribute the difference to the overall decline of the stands outside of ENP rather than differences in wind speed. Because of its proximity to ENP, Navy Wells must have had winds speeds similar to those in the Long Pine Key sites. Furthermore, mortality in several pinelands outside of ENP differed markedly despite similar wind regimes. The smaller size of the stands outside of ENP may have influenced the local wind speed. However, Navy Wells and Deering Estate had relatively large stands with uniform high mortality throughout, while mortality in small stands in ENP did not noticeably differ from that of the larger stands. One possibility is that slow-growing trees, such as those in ENP, have denser, stronger, wood, and may have been more resistant to hurricane damage. However, the extremely high mortality at the Deering Estate, where growth rates were similar to those at the ENP sites, does not support this idea. While wind speed per se does not seem to be directly responsible for mortality patterns, large pines sustained more storm damage than small trees (Loope et al., 1994; Armentano et al., 1995) and sites with an abundance of small trees should have higher survivorship.

The Dade sites have been for the most part have not been fire-managed, and represent a variety of fire histories (Wade et al., 1980), while ENP sites are regularly managed using controlled burns (Armentano et al., 1995). Armentano and co-workers (1995) and Platt and Doren (1995) suggest that fire history was an important factor determining the post-storm mortality of pines, with sites burned during the dry season more susceptible to mortality than sites burned during the lightning fire season (early wet season April–June), such as the Everglades pinelands. Interestingly, they propose water stress as the causal mechanism. Dade sites might also be exposed to more ozone stress (the symptoms of which are similar to the general pine decline seen prior to the hurricane) than sites within ENP. The data of Nowak and McBride (1991) would suggest that trees in urban environments, such as most Dade County Parks, are exposed to more stress overall than trees in natural forests.

Site geology may have played a role in the pattern of mortality. A north–south soil gradient exists along the Miami Rock Ridge (O'Brien, 1996). Although the data do not support N and P differences as important factors for mortality, other undocumented nutrient differences may have played a role in pine susceptibilty to attack.

The final possibility is that chance and stand fragmentation were important factors determining whether or not a stand was decimated. Unlike the smaller Dade County sites, insects may never have attained sufficient numbers in ENP to reach outbreak levels. With the exception of a single stand that burned shortly after the hurricane, the highest post-hurricane mortality within ENP appeared to be in the pine stands at the edge of the main park entrance.

Acknowledgments—This work was supported by The Nature Conservancy contract FLRO-STEW-WP-07-21-94. Additional support came from Florida International University, NSF Grant DEB 9224776, and Department of Interior contract CA-5280-4-9008. We are grateful to Everglades National Park and the Dade County Parks and Recreation Department for permission to sample trees. Dallas Hazelton and Laurie McHargue were extremely helpful in our efforts to obtain tissue for isotope measurements from Dade County Parks. Joe O'Brien kindly produced the map for Fig. 1 and provided the information about physical characteristics of the Dade County Pinelands. Suzanne Koptur and Brad Bennett graciously provided access to microscopes, and Maureen Donnelly and Eric Menges provided critical comments on the manuscript.

LITERATURE CITED

Armentano, T. V., R. F. Doren, T. Mullins, and W. J. Platt. 1995. Effects of Hurricane Andrew on coastal and interior forests of southern Florida: overview and synthesis. J. Coast. Res. 21(Special Issue):111–114.

Atkinson, M. J. and S. V. Smith. 1983. C:N:P ratios of benthic marine plants. Limnol. Oceanogr. 28: 568–574.

Broadmeadow, M. S. J. and H. Griffiths. 1993. Carbon isotope discrimination and the coupling of CO_2 fluxes with forest canopies. Pp. 109–129. *In*: Ehleringer, J. R., A. E.Hall, G. D.Farquhar, and I. P.Ting (eds.), Stable Isotopes and Plant Carbon-Water Relations. Academic Press, New York, NY.

Doren, R. F., W. J. Platt, and L. D. Whitaker. 1993. Density and size structure of slash pine stands in the Everglades region of South Florida. For. Ecol. Manag. 59: 295–312.

EHLERINGER, J. R. AND C. B. OSMOND. 1989. Stable isotopes. Pp 281–300. *In*: PEARCY, R. W., EHLERINGER, J. R., MOONEY, H. A., AND P. W.RUNDEL (eds.), Plant Physiological Ecology, Chapman and Hall, New York, NY.

ELSIK, C. G., R. B. FLAGLER, AND T. W. BOUTTON. 1993. Carbon isotope composition and gas exchange of loblolly and shortleaf pine as affected by ozone and water stress. Pp. 227–244. *In*: EHLERINGER, J. R., A. E.HALL,G. D. FARQUHAR, AND I. P.TING (eds.), Stable Isotopes and Plant Carbon-Water Relations. Academic Press, New York, NY.

EWEL, K. C. AND L. A. PARENDES. 1984. Usefulness of annual growth rings of cypress trees (*Taxodium distichum*) for impact analysis. Tree Ring Bull. 44: 39–43.

GUNDERSON, L. H., S. S. LIGHT, AND C. S. HOLLING. 1995. Lessons from the Everglades. BioScience 45(suppl.): 66–73.

LANGDON, O. G. 1963. Growth patterns of *Pinus elliottii* var. densa. Ecology 44: 825–827.

LOOPE, L., AND G. N. AVERY. 1979. A preliminary report on rare plant species in the flora of National Park Service areas of South Florida. South Florida Research Center Report M-548, Homestead, FL.

———, M. DUEVER, A. HERNDON, J. SNYDER, AND D. JANSEN. 1994. Hurricane impacts on uplands and freshwater swamp forest. BioScience 44: 238–246.

MCHARGUE, L. A. 1994. Metro-dade Park and Recreation Dept, Natural Areas MgtSect., Dade County, FL. Pers. Commun.

MCNULTY, S. G. AND W. T. SWANK. 1995. Wood ^{13}C as a measure of annual basal area growth and soil water stress in a *Pinus strobus* forest. Ecology 76: 1581–1586.

NOWAK, D. J. AND J. R. MCBRIDE. 1991. Comparison of monterey pine stress in urban and natural forests. J. Environ. Manag. 32: 383–395.

O'BRIEN, J. J. 1996. Habitat preferences of rare and common *Galactia* native to southern Florida Pine rocklands. M.S. thesis, Florida International University, Miami, FL.

PLATT, W. J. AND R. F. DOREN. 1995. Immediate and extended effects of Hurricane Andrew on south Florida slash pine stands. Bull. Ecol. Soc. Am. 76(2): 215.

ROBERTSON, W. B., JR. 1955. An analysis of the breeding bird populations of tropical Florida in relation to the vegetation. Dissertation. University of Illinois, Urbana, IL.

ROSS, M. S., J. J. O'BRIEN, AND L. D. S. STERNBERG. 1994. Sea-level rise and the reduction in pine forests in the Florida Keys. Ecol. Appl. 4: 144–156.

RUNDEL, P. W., EHLERINGER, J. R., AND K. A. NAGY. 1988. Stable isotopes in Ecological Research. Ecological Studies, Vol. 68, Springer-Verlag, New York, NY.

SNYDER, J. R., A. HERNDON, AND W. B. ROBERTSON. 1990. South Florida rockland. Pp. 230–277. *In*: MYERS, R. L. AND J. J. EWEL (eds.), Ecosystems of Florida. University of Central Florida Press, Orlando, FL.

TISDALE, R. A. AND M. R. WAGNER. 1991. Host stress influences oviposition preference and performance of pine sawfly. Ecol. Entomol. 16: 371–376.

WADE, D., J. J. EWEL, AND R. HOFSTETTER. 1980. Fire in South Florida Ecosystems. U.S. Department of Agriculture, Forest Service General Technical Report SE-17.

WARD, D. B. 1979. Rare and Endangered biota of Florida: Plants. University Presses of Florida, Gainesville, FL.

Florida Scient. 60(4): 210–222. 1997
Accepted: January 24, 1997.

VOLUMETRIC EXCHANGES BETWEEN A MANAGED MARSH AND A COASTAL ESTUARY

Ashok Pandit(1), John H. White(1), Antonis A. Kakoullis(1), Satish B. Akula(1) and James R. David(2)

(1)Civil Engineering Program, Florida Institute of Technology, Melbourne, FL 32901
(2)St. Lucie County Mosquito Control District, Fort Pierce, FL 34951

Abstract: *The dominant term in the estimation of net flux calculation, between a marsh and a source of tidal water is often the exchange of water. The purpose of this study was to provide a description of the methodology used to estimate the volumetric exchange of surface waters between a managed marsh and the Indian River Lagoon during the managed and unmanaged periods. The paper also documents the simplifying assumptions that had to be made to estimate the exchanges both during the managed and unmanaged period. These assumptions had to be made either because the data were limited mainly due to the cost constraints of the project, or the hydrologic variables were functions of random processes that were difficult to model. The volumetric exchanges during the managed period were computed using direct flow measurements as well as by water balance and the estimated values were within 4.4 percent of each other. The exchanges during the unmanaged period were computed using only direct flow measurements. During the unmanaged period, the bulk of the water is exchanged during mid tide but the magnitude of the exchange depends on the high tide elevation.*

In his review of twenty years of research on the role of salt marshes in estuarine productivity, Nixon (1980), compiled the methods used in determining water exchanges between salt marshes and estuaries, as well as their uncertainties and drawbacks. He reported that virtually all of the studies used one of two methods in determining exchange volumes. The first method consisted of using flow meters to determine direct discharges (Boon 1975 and 1978; Kjerfve et al., 1978; Kjerfve and Proehl, 1979; Valiela et al, 1978). The second method estimated volumetric exchanges using information on tide heights and hypsographic curves. Boon (1975) also performed a detailed comparison of both methods in a Virginia marsh and concluded that " . . . the determination of time-varying tidal discharge by means of an area-height model, rather than by direct flow measurements, is not recommended for the calculation of net transport." The purpose of this study was to determine and compare the volumetric exchange of surface waters between a managed marsh in St. Lucie County, Florida, and the Indian River Lagoon during the managed and unmanaged period. The volumetric exchanges during the managed period were computed using direct flow measurements as well as by water balance. The exchanges during the unmanaged period were computed using only direct flow measurements.

A brief description of marsh management practices in Saint Lucie County is provided so that the readers can understand the term "managed marsh". Since 1935, dikes were installed around the marshlands in St. Lucie County and the water from the marshlands was pumped out into the Indian River Lagoon for the control of sandflies. Soil was excavated from within the "impounded" marshlands, also known as impoundments, to build these dikes and the resulting depressions created a ditch, termed as the perimeter ditch, along the estuarine periphery of the impoundments. The dike constructions, however, caused a loss of estuarine-marsh connections and resulted in the physical isolation of the salt-marsh and mangrove habitats from the waters of the Indian River Lagoon. As a result, a two-phase marsh restoration program, known as Rotational Impoundment Management (RIM), began in 1984 and is currently on going in St. Lucie County. First, culverts are being installed through the dikes to hydraulically connect the lagoon and the marsh and to provide free flow between these two water bodies. These culverts allow for life-sustaining water quality in the marsh and access to the marsh by aquatic life in the lagoon. Second, water circulation is being created within marshes during the summer months (management period) by pumping lagoon water into one end of the marsh and releasing it back into the lagoon at the other end through specifically constructed tide-gates attached to culverts. Marshes, which are managed by this type of water circulation, are termed "managed" marshes.

Water, during the managed period, is released by bottom-water-release culverts or overflow culverts. A bottom water release culvert allows poor quality impoundment water, with a high BOD, to be released into the lagoon from a depth of approximately 1 m. An overflow culvert allows surface water to be released from the impoundment into the lagoon. A managed marsh undergoes three periods; a managed period which is usually from May 1 through August 31; a transitional period, usually from September 1 to October 31, during which tide gates are removed and pumping is gradually stopped; and the remainder "open" period during which water flows freely between the lagoon and the marsh based on tidal conditions

STUDY LOCATION AND CULVERT DESCRIPTION—The study location was a managed marsh in Hutchinson Island which is in Saint Lucie County, Florida. Hutchinson Island forms the eastern boundary of the county, and also separates the Indian River Lagoon from the Atlantic Ocean (Fig.1). The western fringe of Hutchinson Island consists of mangrove swamps and high salt-marshes. The location of Impoundments 1 through 11A–B are also shown (Fig.1). Impoundment 2, which is located west of highway AIA (N 27° 25′ 30″; W 80° 16′ 30″) in St. Lucie County and extends over an area of 76 ha (188 acres) (Figure 2), was selected for the purpose of this study. Water flows between the impoundment and the Indian River Lagoon through seven 0.76 m diameter corrugated aluminum culverts (numbered A through G in Fig. 2), which connect the lagoon to the perimeter ditch. These culverts are approximately 12.2 m long. In addition to these seven culverts, there are three 1.2 m diameter culverts (marked as H, I, and J in Fig. 2), within the impoundment which connect the east and west ends of the impoundment situated on either side of state road A1A. Water is continuously pumped from the lagoon at the north end of the impoundment during the managed period and the marsh water is discharged back into the lagoon through four surface water release (or overflow)

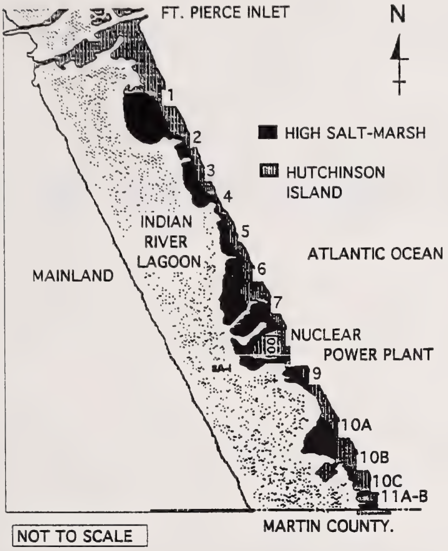


FIG. 1. Locations of some of the impounded marshes within Saint Lucie County.

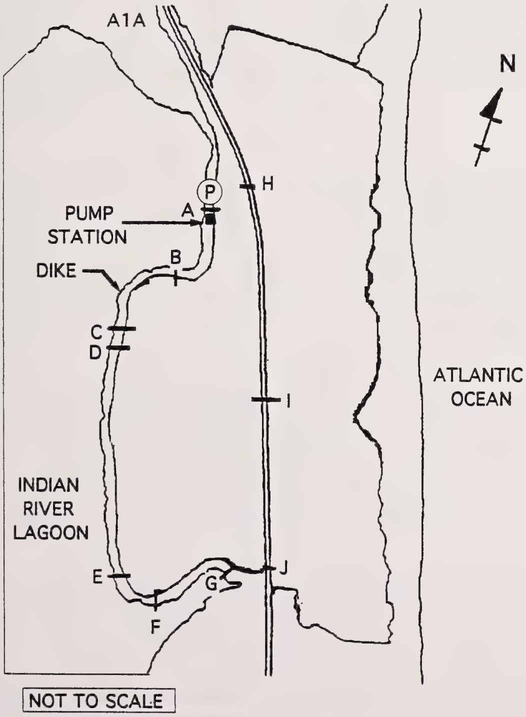


FIG. 2. Map of Impoundment 2 showing culvert locations.

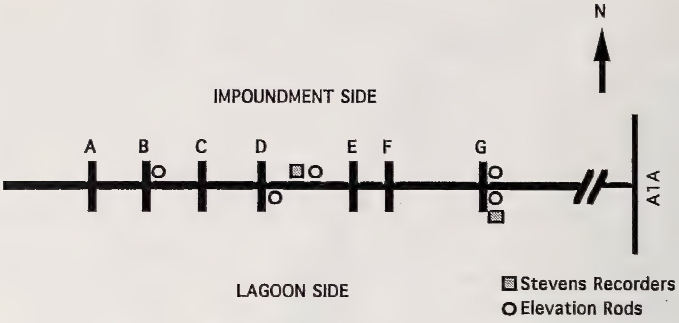


FIG. 3. Locations of continuous water level recorders and elevation rods.

culverts, culverts B, C, D, and F, and two bottom-water-release culverts, culverts E and G. As noted earlier, the tide gates are removed from all culverts during the unmanaged period, and there is unrestricted flow between the impoundment and the lagoon through the culverts during this period.

Culvert A is closed during the managed period because of its proximity to the pump station. This is done in an attempt to maintain a constant water level within the impoundment. In 1991, the pump was switched on June 15, 1991, although data collection began from July 8, 1991. The managed period in 1991 was, therefore, from June 15 to September 5. Tide gate weirs attached to the culverts were removed while the pump remained in operation during a transition period between September 6 and September 30, 1991. The pump was turned off on September 30, 1991, and the unmanaged period occurred between October 1 and April 30, 1992. During the unmanaged period, water exchange between the impoundment and lagoon was unregulated, with the direction of flow dependent on the lagoon and impoundment water elevations.

METHODS—Continuous water level measurements were taken in Impoundment 2 between July 9, 1991 and May 1, 1992 although some data were lost due recorder malfunction, moisture leakage through the wooden housing, insects, and vandalism. The locations of two continuous stage recorders and five elevation rods, also installed for measuring water elevations, are shown in Figure 3. Figure 4 is a fair representation of the water levels measured during the managed period. The impoundment water level, during the managed period, remained relatively constant between 0.52 m and 0.64 m above the National Geodetic Vertical Datum (NGVD) although relatively small abrupt rises and falls were observed during and after rainfall events. The lagoon water elevations during this period ranged from 0.14 m below NGVD to 1.0 m above NGVD. Figure 5 is indicative of the data measured during the unmanaged period. During this period, there were tidal fluctuations in both the lagoon and impoundment water levels with a lag of approximately one hour between the impoundment and lagoon high and low water levels. Lagoon water levels ranged from 0.07 m below NGVD to 0.78 m above NGVD during this period with a maximum tidal range of 0.44 m. Marsh water levels ranged form 0.05 m below NGVD to 0.68 m above NGVD during this period with a maximum tidal range of 0.36 m.

Estimation of flow rates through culverts-managed period—During the managed period, velocities were measured at the lagoon end of the culverts on August 30 and September 3, 1991, at all culvert locations with the exception of location A (since it was closed) using a Marsh-McBirney Model 527 Electromagnetic Water Current Meter. The lagoon water level was rising during the measurement period on both days. Velocities were measured across the culvert cross-section at three locations and an average velocity was computed. The difference in the lagoon and marsh water levels, h, was also recorded at the same time.

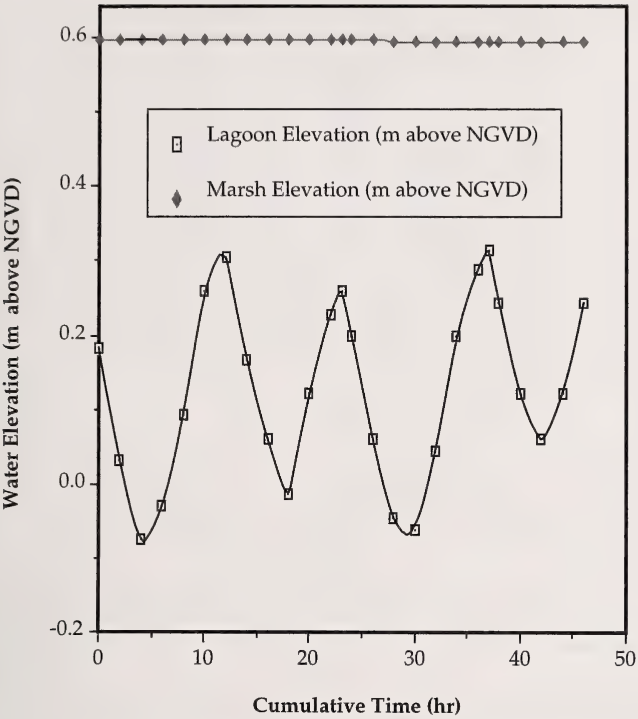


FIG. 4. Lagoon and marsh water level elevations during the managed period (from 1:45 AM on August 15 to 11:45 PM on August 16, 1991).

Culvert discharges (or flow rates), Q, were calculated by multiplying the average velocity by the submerged area. An attempt was made to develop a rating curve for each culvert by plotting graphs between Q and h. However, there was extreme scatter in the data plotted between the two variables. This scatter was most likely due to the fact that debris such as leaves, sticks and other objects, gathered at the overflow inlet, had more influence on the flow rate through the culvert than the head differential between the lagoon and impoundment water levels. This is evident from the data shown in Table 1; the flow rate remained fairly steady (standard deviations in the range of 0.01 m^3/s to 0.02 m^3/s) while the h values ranged from 0.17 m to 0.47 m. Rating curves, developed after cleaning the debris, would not have been useful in future projections since the debris would have reassembled at the overflow inlets. In the absence of meaningful rating curves, it was decided to use the average flow rates (Table 1) to estimate volumetric exchanges through overflow culverts. This approximation, although seemingly crude, can be justified by the fact that the standard deviations in the measured flowrate values were relatively small (which implies that the flowrates remained close to the average value) even though there was a 0.3 m differential in the measured h values.

The data between Q and h for the two bottom water release culverts, culverts E and G, were better correlated as shown in Figures 6 and 7, respectively. These figures show the rating curves obtained at these culverts in August 1991 and August 1992, respectively. In 1991, some of the flow data for culvert G was lost due to equipment malfunction. The rating curves were, therefore, also determined in 1992. The rating curves of 1992 are lower because 1992 had a relatively dry summer and the bottom water release culverts were opened to a lesser degree, thus allowing the water to be discharged at a lower flow rate compared to 1991. The 1992

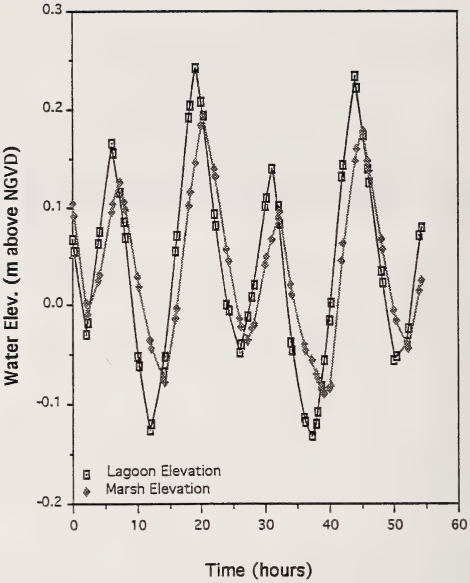


FIG. 5. Lagoon and marsh water level elevations during the unmanaged period (from 1:45 AM on August 15 to 11:45 PM on August 16, 1991).

rating curves were not used for estimating the volumetric exchanges in 1991; they are shown for comparison purposes and to indicate that the slope and location of the 1991 rating curve for culvert G appears to be accurate even though it is based on just three data points. Linear relationships (Eqn. 1 and 2) were obtained from the graphs

$$Q_E = 4.6751 + 6.1469h \tag{1}$$

$$Q_G = -2.2759 + 19.687h \tag{2}$$

where Q_E and Q_G are the respective flow rates (m^3min^{-1}) for culverts E and G.

Unmanaged period—During the unmanaged period, velocity measurements were taken on March 25, September 11, September 25, and October 8, 1992, using a Model 2031H2 General Oceanics Low-Speed Current meter. The high tide elevations on these days varied from 0.28 m NGVD (March 25) to 0.68 m NGVD (October 8). Velocities were measured at all culvert sites on March 25 and September 11 but were measured only at culverts A and G on the other days. Measurements were taken, approximately every 45 minutes, at three locations across the

TABLE 1. Average flowrates and standard deviations for the overflow culverts.

Culvert	No. of Measurements	Flow Rate Range cm*	Average cm*	Standard Deviation cm*
B	6	0.03–0.07	0.05	0.01
C	6	0.05–0.08	0.07	0.01
D	11	0.05–0.10	0.09	0.02
F	7	0.05–0.09	0.07	0.01

* m^3/sec.

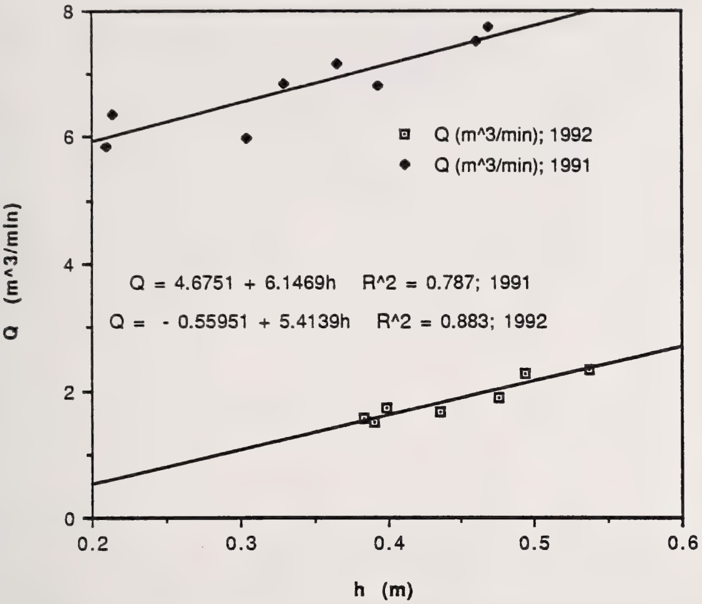


FIG. 6. Rating curves of the bottom water release culvert 2E. The water level difference between the marsh and the lagoon is designated by h.

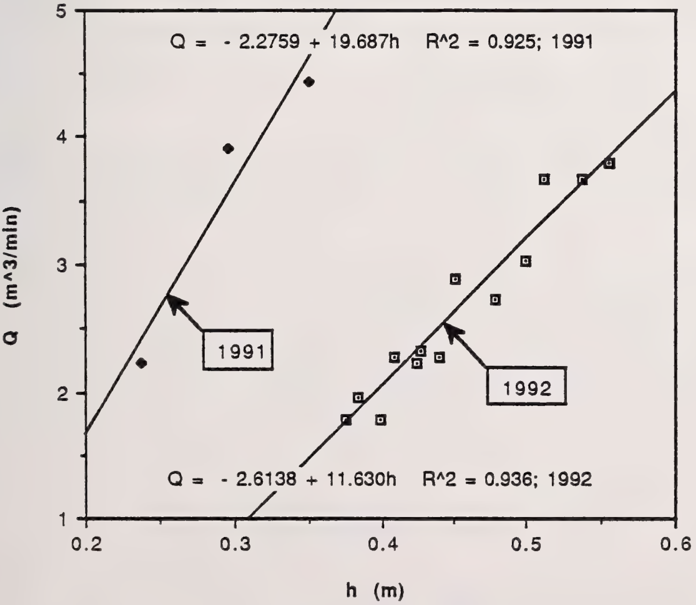


FIG. 7. Rating curves of the bottom water release culvert 2G. The water level difference between the marsh and the lagoon is designated by h.

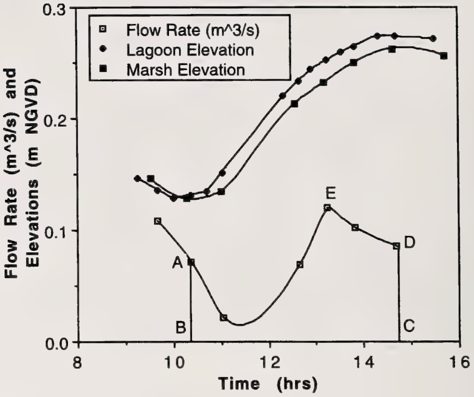


FIG. 8. Variation of marsh and lagoon water levels and flowrates through culverts with time.

culvert cross-section, and an average value was calculated. The water elevations in the lagoon and the impoundment were also noted at the same time.

Again, it was initially expected that the flowrate through the culverts would be a function of the head difference between the lagoon and impoundment water levels. However, graphs plotted between these two variables once again showed no consistent relationship for any of the culverts. On the other hand, graphs between estimated flow rates, lagoon water levels and impoundment water levels versus time, such as the one shown in Fig. 8, were more revealing. These graphs showed that flow rates were lowest when the lagoon and marsh water levels were equal, i.e., shortly after high and low tides in the lagoon, and reached a maximum value somewhere in the middle of the tide. Graphs for all other culverts were very similar to the one shown in Fig. 8. The flow rates plotted in Fig. 8 are absolute values and do not reflect the direction of flow. The direction of flow, however, can be determined from the change in impoundment water level; if the impoundment water level is increasing, the flow is into the impoundment otherwise it is into the lagoon.

The average flow rate for each culvert was found by dividing the area under the flow rate curve (area ABCDE on Fig. 8) by the time interval (duration between B and C on Fig. 8). The estimated average flow rates using this method, based on data collected on various days, are shown in Table 2. The high tide elevation at the time of measurement, and the average flow rates for all culverts on the four days that data were measured are also noted in this table. A comparison of these values clearly shows that flow rates are higher when the lagoon tides are high, i.e., more water is exchanged between the marsh and the lagoon if the hightide elevation is relatively higher. The cumulative flow rates through all culverts, which were determined by multiplying the average flow rate by seven (number of culverts), are also shown (Table 2).

An exponential rating curves provided the best fit ($r^2 = 0.813$) between high tide elevation and the cumulative flow rate through all culverts, based on the data collected on March 25, September 11, September 16, and October 8, 1992. The range of measured high tide elevations on these dates were from 0.28 m NGVD to 0.68 m NGVD (Table 2) and the equation for the rating curve was found to be:

$$y = (0.26)10^{(1.63x)} \tag{3}$$

where y is the cumulative flow rate (m^3s^{-1}) through all culverts and x is the high tide elevation (m). A second order polynomial fitted the data points more precisely but was rejected on the basis that it showed a decreasing trend, i.e., flow rate decreased as high tide elevation increased after the maxima on the curve.

TABLE 2. Measured average and cumulative flowrates (in cubic meters per second) at different high-tide elevations in Impoundment 2.

Culvert	High-Tide Elevation 0.28 m	0.29 m	0.46 m	0.68 m
A	0.070	0.100	0.327	0.396
B	0.072	0.135	NM	NM
C	0.083	0.122	NM	NM
D	0.097	0.139	NM	NM
E	0.077	0.125	NM	NM
F	0.076	0.151	NM	NM
G	0.057	0.121	0.316	0.411
Average	0.076	0.128	0.322	0.404
Cumulative	0.532	0.893	2.251	2.825

Note: NM implies not measured.

Estimation of pumped flow rates—Tests were conducted by the company of Knight and Mathis to determine the rate at which water was discharged into the marsh from the pump station using a Doppler flow meter. These tests measured a pump flow rate of 28.6 m^3min^{-1}. The margin of error for the test was stated to be 0.2 m^3min^{-1}. These tests were conducted when the lagoon water level was approximately 0.76 m below the discharge pipe elevation.

RESULTS—*Estimation of volumetric exchanges during the managed period from direct measurements*—Volumetric exchanges between the lagoon and the impoundment through the bottom water release culverts E and G were estimated by Eqns. (1) and (2). The incremental flow volume, V_{BWR}, that was discharged through these culverts, during interval Δt, was calculated as follows:

$$V_{BWR} = \{[Q_{(E)t=0} + Q_{(E)t=t+\Delta t}]/2 + [Q_{(G)t=0} + Q_{(G)t=t+\Delta t}]/2\}(\Delta t) \quad (4)$$

where $Q_{(E)t=0}$ and $Q_{(G)t=0}$ are the flow rates through E and G at the beginning of the interval, and $Q_{(E)t=t+\Delta t}$ and $Q_{(G)t=t+\Delta t}$ are the flow rates through E and G at the end of the interval. The time period, Δt, was selected as two hours and the difference in water levels, h, was computed at every two hours. The incremental flow volume, V_O, that was discharged through the overflow culverts, A, B, C, D and F, was obtained by multiplying the cumulative average flow rates shown in Table 1 by Δt. Approximately 2.7 million m^3 (270 ha-m) of water was discharged into the lagoon from the impounded marsh through the culverts during the managed period over a period of 59 days (from July 9 to September 5) at an average rate of 31.8 m^3 min^{-1}.

Estimation of volumetric exchanges during the managed period by water mass balance—The water balance equation for the marsh during the managed period can be written as:

$$P + R_L = D + ET + GWD + S \quad (5)$$

where P is the rainfall, R_L is the water pumped from the lagoon, D is the outflow from the impoundment through the culverts, ET is the loss due to evapotranspiration, GWD represents the ground water discharge, and S is the water stored into the marsh during the managed period. If at no time is there a deficiency of water in the soil for vegetation use, then Eqn.(4) can be rewritten as:

$$P + R_L = D + PET + GWD + S \tag{6}$$

in which PET is the annual potential evapotranspiration. Viessman and coworkers (1977) suggested that in practice PET is equal to lake evaporation (LE) as determined from National Weather Service Class A records. Therefore, Eqn. (5) can be further reduced to:

$$P + R_L = D + LE + GWD + S \tag{7}$$

There was no appreciable storage in the marsh since the water level within the marsh did not change except during storm events, i.e., S = 0. Therefore, Eqn. (7), after rearrangement, can be modified to:

$$D = P + R_L - LE - GWD \tag{8}$$

The total rainfall from July 9 to September 5 was 0.42 m, the lagoon water pumped into the marsh was 3.20 m, and the pan evaporation was 0.33 m. The actual evaporation from the marsh during the managed period was estimated to be 0.23 m assuming a pan coefficient of 0.7. If groundwater seepage is considered negligible compared to the other terms in Eqn. (8), then D = 3.4 m from Eq (8) and the estimated volume discharged into the lagoon is 258 ha-m. The volumetric discharges computed by water balance is within 4.4 % of the volumetric discharge estimated by direct measurement (270 ha-m).

Estimation of volumetric exchanges during the unmanaged period—Estimations of the volume of water exchanged between the impoundment and the lagoon, using the exponential model are shown in Table 3. The procedure used to estimate the volume of water exchanged between the lagoon and the marsh between the two high tides occurring at 9:45 AM and 9:30 PM is described subsequently. Since the impoundment water elevation was dropping from 9:45 AM to 3:45 PM (column 2) from 0.27 m NGVD to 0.16 m NGVD (column four) during a period of 6.00 hours (column three), the flow direction, during this period, was from the impoundment into the lagoon. Similarly, since the impoundment water elevation was rising from 3:45 PM to 9:30 PM (column 2) from 0.16 m NGVD to 0.18 m NGVD (column four) during a period of 5.75 hours (column three), the flow direction, during this period, was from the lagoon into the impoundment. The cumulative flow rate through all culverts at 9:45 AM and 9:30 PM were calculated from Eq. 3 (column 5) and the average cumulative flow rate during this period is tabulated in column 6. Finally, the volume of water into lagoon (column 7)

TABLE 3. Sample volume calculations with the exponential model in Impoundment 2 during the unmanaged period.

Date 1	Time 2	Time Interval (hours) 3	Water Elevation (in NGVD) 4	Flowrate (cm)* 5	Average Flowrate (cm)* 6	Volume into Lagoon (cubic meters) 7	Volume into Impoundment (cubic meters) 8
12/1/91	2:15 AM		0.14				
	9:45 AM	7.50	0.27	0.361			
	3:45 PM	6.00	0.16		0.342	7392	
	9:30 PM	5.75	0.18	0.324			7084
12/2/91	2:30 AM	5.00	0.03		0.323	5816	
	12:00 PM	9.50	0.18	0.323			11050
	3:45 PM	3.75	0.11		0.314	4243	
	11:00 PM	7.25	0.13	0.306			8202
12/3/91	3:00 AM	4.00	0.02		0.312	4493	
	12:15 PM	9.25	0.16	0.318			10391
	4:15 PM	4.00	0.05		0.313	4501	
	9:15 PM	5.00	0.13	0.317			5626

* m^3/sec.

or the volume of water into impoundment (column 8) is calculated by multiplying the respective numbers in column 3 and column 6.

The monthly volumes exchanged between the lagoon and the marsh during the unmanaged period are shown in Table 4. A comparison of the average monthly volumes exchanged between the marsh and the lagoon during the unmanaged period indicates that the highest exchanges occurred during the months of October and November which are also the months in which the tides are highest. July and August numbers were not averaged because these months were during the managed period, and the flow, during these months, was only in one direction, i.e., from the marsh to the lagoon. It can also be noted from Table 4 that the monthly volumes discharged into

TABLE 4. Estimated monthly volume exchanges in 1991–1992.

Month	Volume into Lagoon (mil. cubic meters)	Volume into Impoundment (mil. cubic meters)	Average Exchange Volume (mil. cubic meters)
July	1.44	1.28	—
August	1.45	1.28	—
September	*	*	*
October	2.17	2.07	2.12
November	2.32	1.92	2.12
December	0.93	0.92	0.92
January	1.21	1.07	1.14
February	1.09	1.01	1.05
March	0.83	0.68	0.76
April	1.18	1.00	1.09

the lagoon were always estimated to be greater than the monthly volumes discharged into the marsh. These differences occur mainly for two reasons. First, some of the rainfall is also discharged into the lagoon during the storm periods. Second, it is assumed that for a given tidal height, the average flow rate during an ebb tide is equal to the average flow rate during the flood tide. This assumption could also lead to the observed discrepancies since it was noted that the average duration of the flood tide (when water is discharged into the marsh) for the month of December was 5.78 hours while the average duration of the ebb tide was 6.63 hours. It was assumed for the purpose of this study that the actual monthly volume exchanged was the average of the estimated discharges into the lagoon and the marsh.

DISCUSSION—Nixon (1980) pointed out that the dominant term in the estimation of net flux calculation, between a marsh and a source of tidal water is often the exchange of water. An effort has been made to describe, in detail, the somewhat tedious methodology that has to be used to estimate the volumetric exchanges between a tidal estuaries and managed marshes. A number of simplifying assumptions had to be made to estimate the exchanges both during the managed and unmanaged period. These assumptions had to be made either because the data were limited mainly due to the cost constraints of the project, or the hydrologic variables were functions of random processes that were difficult to model. For example, it was noted that the flow rate from the overflow culverts, during the managed period were, to an extent, a function of leaves and other debris accumulating over weirs. Volumetric exchanges were, therefore, also estimated by the water balance equation and the results obtained from the two methods were fairly close (within 4.4 percent).

An examination ofwater levels measured during the unmanaged period (Fig. 5) shows that the there were times when there was considerable difference in the water levels at low and high tides. Yet flow measurements at this time showed almost no flow through the culverts. This is why we could not obtain the expected rating curve between flowrate and the elevation difference between lagoon and marsh water levels. The bulk of the water was exchanged during mid tide and not during the high or low tide when the water reverses direction from the marsh to the lagoon or vice versa. However, the magnitude of the exchange during a tidal cycle depends on the high tide elevation and much greater volumes of water were exchanged when high tide elevations were 0.5 m or higher.

ACKNOWLEDGMENTS—The financial support provided by the South Florida Water Management District through the Indian River Lagoon SWIM program and the St. Lucie County Mosquito Control District is gratefully acknowledged.

LITERATURE CITED

BOON, J., III. 1975. Tidal discharge asymmetry in a salt marsh drainage system. Limn. Oceanogr. 20: 71–80.

———. 1978. Suspended solids transport in a salt marsh creek—an analysis of errors. Pp 147–159. In: KJERFVE, B. (ed.), Estuarine Transport Processes, University of South Carolina Press. Columbia, SC.

KJERVE, B., J. E. GREER AND R. L. CROUT. 1978. Low-frequency response of estuarine sea level to non-local forcing, pp 497–513. *In*: WILEY, M. L. (ed.), Estuarine Interactions. Academic Press. New York, N Y.

——— AND J. A. PROEHL. 1979. Velocity variability in a cross-section of a well-mixed estuary. J. Mar. Res. 37: 409–418.

NIXON, S. W. 1980. Between coastal marshes and coastal waters-A review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. Pp 476–481. *In*:HAMILTON, P. AND MCDONALD, K. B. (eds.) Estuarine and Wetland Processes with Emphasis on Modeling. Plenum Publishing, New York, N. Y.

VALIELA, I., J. M. TEAL, S. VOLKMAN, D. SHAFER, AND E. J. CARPENTER. 1978. Nutrient and particulate fluxes in a salt marsh ecosystem: tidal exchanges and inputs by precipitation and groundwater. Limn. Oceanogr. 23(4): 798–812.

VIESSMAN, W., JR., J. W. KNAPP, G. L. LEWIS, AND T. E. HARBAUGH. 1977. Introduction to Hydrology, 2nd edition, Harper & Row,. Publishers, New York, NY.

Florida Scient. 60(4): 223–235. 1997
Accepted: February 28, 1997.

HIGH BREEDING DENSITY OF COMMON MOORHENS AT A ZOOLOGICAL PARK

BRETT K. BANNOR

Metrozoo, 12400 Southwest 152 Street, Miami, Florida 33177

ABSTRACT: *Nesting densities reported for the Common Moorhen (*Gallinula chloropus*) in North American wetlands are usually 5.5 pairs per hectare or less. From 1994 through 1996, I studied nesting activity of free-ranging moorhens inhabiting an exhibit of captive aquatic birds at Miami Metrozoo. During peak reproductive periods of all three years, seven to eight pairs or trios of moorhens simultaneously brooded eggs or raised chicks in this 0.4 ha artificial lake, a density equal to 17.5 to 20 pairs/ha. Access to supplemental food probably was responsible for this high nesting density.*

IN EMERGENT marshes of North America, the Common Moorhen (*Gallinula chloropus*) typically has a breeding density of 5.5 pairs or fewer per hectare (Beecher, 1942; Weller and Fredrickson, 1973; Brackney and Bookhout, 1982; Post and Seals, 1991; but see Miller, 1946). Here, I summarize a 3-year study of nesting by non-captive moorhens at a manmade lake with no emergent zone at Miami Metrozoo in suburban Dade County, Florida. These moorhens showed a substantially greater breeding density than reported in other studies conducted in North America.

STUDY AREA—The Metrozoo waterfowl-flamingo lake is an 0.4 ha water-filled, concrete basin with a mean depth of 0.7 m (range 0.5 to 1.0). Its length is approximately 198 m; width varies from 7.5 to 53.5 m. Poured concrete sides of the lake extend above the water forming an abrupt, artificial shoreline; this concrete lip extends landward for 0.3 to 0.6 m. Beyond is a zone of ornamental plantings <1.0 to 7.0 m wide. This landscaped buffer is the site of most moorhen nests and is surrounded on all sides by paved sidewalks and service roads. Every November the lake is drained, cleaned, and refilled. Because of the lake's construction and its maintenance, the water lacks an emergent zone or submergent vegetation other than filamentous algae.

METHODS—From January 1994 through December 1996 I monitored moorhen reproduction in the lake. When behavior of the birds indicated a nest might be present, I attempted to locate it. I did not find all nests, but the later appearance of chicks accompanying the adults often confirmed suspected nestings.

The moorhens were not marked or banded. Instead, I carefully noted the synchrony of clutches and broods to ensure that I was accurately counting the number of nesting pairs and trios in the lake. The production of multiple broods by most of the pairs also facilitated identification, because the juvenile moorhens' habit of feeding younger chicks (e. g., Eden, 1987) often provided a continuity marker as successive broods hatched.

RESULTS—Between March and September of 1994 and 1995, seven pairs or trios of moorhens simultaneously brooded eggs or raised chicks, a density equivalent to 17.5 pairs/ ha. During the same period in 1996, eight pairs or trios simultaneously nested or reared chicks, a density equivalent to 20 pairs/ ha.

Although I did not determine the size or boundaries of each moorhen territory, I observed that some nests were closely spaced. For example, in 1995 four pairs or trios nested simultaneously within a 130 m^2 area of lake and shoreline; the two closest nests were only 7 m apart. Chicks hatched in all four nests between 26 July and 18 August.

I did not monitor nests for conspecific brood parasitism (e.g., McRae, 1995). Two lines of evidence suggest, however, that the high nesting density did not result in correspondingly high brood parasitism. First, the 30 nests for which a clutch size could be determined had a mean clutch size of 7.5 (range 4 to 12) and a mode of 7 (9 nests), figures normal for a single laying female (Greij, 1994). Second, only two nests had more than nine eggs; one of these, a 1996 nest with twelve eggs, was defended by three adults when I inspected it, indicating that the large clutch was due to cooperative nesting rather than brood parasitism (e.g. Gibbons, 1986).

DISCUSSION—Since the lake lacks aquatic vegetation besides algae, the emergent and submergent plants that comprise the bulk of the Common Moorhen's natural diet in Florida (e.g. Mulholland and Percival, 1982) are absent. However, since the lake is a zoo exhibit, food is readily available. A variety of commercially prepared animal foods is set out daily at four feeding stations to sustain the captive birds. In addition, three times daily zookeepers cast waterfowl food pellets upon the lake in several places, and coin-operated feeders allow the public to toss fish chow pellets to the lake's birds and fish. Moorhens were regularly observed eating all the various foods provided. Apparently the Metrozoo moorhens thrived and maintained an unnaturally high nesting density in sub-optimal habitat because of an artificial abundance of food.

The extent to which food supply affects Common Moorhen breeding biology is not clear. Siegfried and Frost (1975) concluded that food availability triggers opportunistic breeding, but Petrie (1984) showed no correlation between territory size of nesting birds and food supply. Supplemental feeding experiments by Eden (1987) and by Eden and co-workers (1989), did not consider nesting density.

Some species of birds may be strongly influenced by supplemental feeding. For instance, Heusmann (1988) concluded that the Mallard (*Anas platyrhynchos*) is able to winter in far greater numbers in the northeastern United States today than it did historically because of food provided in parks.

Several researchers have concluded that the Common Moorhen is strongly territorial. Petrie (1984) found that 50 moorhen pairs nesting in drainage ditches in England defended an average of 149.4 m of linear ditch bank from conspecifics. Likewise, in a survey of 52 English farm ponds (largest 0.15 ha), Relton (1972) found none had more than one pair of moorhens. Relton believed that intraspecific aggression in the breeding season prevented more than a single pair of moorhens from inhabiting any one pond.

In this study, however, I observed as many as eight simultaneously nesting pairs or trios of moorhens in a 0.4 ha artificial lake deficient in natural food but having abundant and reliable supplemental food. Accordingly, the lower nesting densities reported in previous studies of Common Moorhens may be related to limited availability of food rather than to the intrinsic aggressive nature of the bird.

ACKNOWLEDGMENTS—I thank my colleagues at Metrozoo, C. Burch, S. Conners, D. Hill, and S. Kong; as well as J.A. Bueno of Florida International University and J. Lowe of the Cornell Laboratory of Ornithology. Earlier drafts of the text benefited from the advice of D. Lindburg, C.R. Chandler, D.F. Martin, T. Bookhout, and anonymous reviewers.

LITERATURE CITED

BEECHER, W. J. 1942. Nesting Birds and the Vegetation Substrate. Chicago Ornithological Society, Chicago, IL. 69 pp.

BRACKNEY, A. W. AND T. A. BOOKHOUT. 1982. Population ecology of Common Gallinules in southwestern Lake Erie marshes. Ohio J. Sci. 82:229–237.

EDEN, S. F. 1987. When do helpers help? Food availability and helping in the moorhen, *Gallinula chloropus*. Behav. Ecol. Sociobiol. 21:191–196.

———, A. G. HORN, AND M. L. LEONARD. 1989. Food provisioning lowers inter-clutch interval in moorhens, Gallinula chloropus. Ibis 131:429–432.

GIBBONS, D. W. 1986. Brood parasitism and cooperative nesting in the moorhen, *Gallinula chloropus*. Behav. Ecol. Sociobiol. 19:221–232.

GREIJ, E. D. 1994. Common Moorhen. Pp. 144–157. *In*:TACHA, T. C. AND C. E. BRAUN (eds.) Migratory Shore and Upland Game Bird Management in North America. International Association of Fish and Wildlife Agencies, Washington, DC. 223 pp.

HEUSMANN, H. W. 1988. The role of parks in the range expansion of the Mallard in the Northeast. Pp. 405–412. *In*: WELLER, M. W. (ed.) Waterfowl in Winter. University of Minnesota Press, Minneapolis, MN. 624 pp.

MCRAE, S. B. 1995. Temporal variation in responses to intraspecific brood parasitism in the moorhen. Anim. Behav. 49:1073–1088.

MILLER, R. F. 1946. The Florida gallinule: breeding birds of the Philadelphia region. Cassinia 36:1–16.

MULHOLLAND, R. AND H. F. PERCIVAL. 1982. Food habits of the Common Moorhen and Purple Gallinule in north-central Florida. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies. 36:527–536.

PETRIE, M. 1984. Territory size in the moorhen (*Gallinula chloropus*): an outcome of RHP asymmetry between neighbours. Anim. Behav. 32:861–870.

POST, W. AND C. A. SEALS. 1991. Bird density and productivity in an impounded cattail marsh. J. Field Ornithol. 62:195–199.

RELTON, J. 1972. Breeding biology of moorhens on Huntingdonshire farm ponds. Brit. Birds 65:248–256.

SIEGFRIED. W. R. AND P. G. H. FROST. 1975. Continuous breeding and associated behaviour in the moorhen, *Gallinula chloropus*. Ibis 117:102–109.

WELLER, M. W. AND L. H. FREDRICKSON. 1973. Avian ecology of a managed glacial marsh. Living Bird 12:269–291.

Florida Scient. 60(4): 236–238. 1997
Accepted: March 21, 1997

BEHAVIOR OF SEA TURTLES AT AN URBAN BEACH III. COSTS AND BENEFITS OF NEST CAGING AS A MANAGEMENT STRATEGY

STEPHANIE L. ADAMANY(1), MICHAEL SALMON(1,2), AND
BLAIR E. WITHERINGTON(3)

(1)Department of Biological Sciences, Florida Atlantic University, 777 Glades Road, Box 3091, Boca Raton, Florida 33431;
(3)Florida Department of Environmental Protection, Tequesta Field Station,
19100 SE Federal Highway, Tequesta, Florida 33469

ABSTRACT: *At a sea turtle nesting beach in Boca Raton, Florida, all nests are covered with a wire cage to protect the eggs from beach traffic and predators. The front panel of the cage (facing the ocean) is of larger mesh that allows hatchlings to escape. In this study we determined if cages impede hatchling migration. No effect was apparent at dark beach sites but at illuminated beach areas, hatchlings crawled toward lights behind the beach rather than toward the ocean, and were trapped within the cage. Trapped turtles eventually escaped, either later that evening (as lighting was reduced toward midnight) or at dawn (as natural levels of background illumination increased). However at night, enough lighting remained to attract turtles after they left the cage. At dawn, escaped hatchlings crawled to the sea but were probably vulnerable to visual predators. We conclude that at urban sites exposed to luminaires, cage use compromises hatchling survival. Thus at urban rookeries, caging is only effective if coupled with efforts to eliminate beach-front lighting.*

OCEANIC beaches on Florida's East coast serve as a rookery for Western Atlantic loggerhead turtles (*Caretta caretta* L.), the second largest extant population of this species in the world (Ehrhart, 1989). Most of the turtles nest at northeastern coastal regions where there is relatively little beach-front development, and where levels of artificial lighting at beach sites are low (Meylan et al., 1995). A significant minority of loggerheads nest at beaches in South Florida bordering suburban communities and cities. At these habitats, recreational use of beaches is heavy and nesting sites are often exposed to artificial lighting.

At the city of Boca Raton, Florida, U.S.A., the nesting beach is backed by parks or by rows of condominiums. Tall trees within the parks, and high condominiums along the beach, act as barriers which shield some beach areas from city lighting. These dark beach areas contain many nests (Salmon et al., 1995a) but even in these locations, distant sources of artificial lighting can cause hatchlings to crawl toward land instead of toward the ocean (Salmon et al., 1995b).

---

[2] Request reprints from M. Salmon.

Many visitors to the beach (approx. 22,550/month) also pose a threat to sea turtle nests. Beach equipment may penetrate the nest, killing eggs. Sand compaction by foot traffic, and debris left on the beach, may hamper or prevent the hatchlings from digging their way to the surface (Magnuson et al., 1990). Nests may also be disturbed by human digging or walking, which can cause hatchlings to emerge prematurely (after they exit the egg but before they have absorbed all external yolk), or during the daylight hours when they may be overcome by high sand temperatures (Mrosovsky, 1968; Bustard, 1972). City parks at Boca Raton also support large numbers of raccoons *(Procyon lotor),* that are significant egg and hatchling predators (Stancyk, 1982).

Since 1988, the city has protected nests by covering them with square wire cages, open at the bottom where they are anchored into the sand. Cages are constructed of fine mesh screening on the top, side and rear (landward facing) panels; the front panel, facing the ocean, is of larger mesh that allows hatchlings to escape while excluding predators. Cages are placed over a nest the morning after the clutch is deposited on the beach, and removed several days after the hatchlings emerge.

While cages protect nests from predators and foot traffic, nothing is known about how emerging hatchlings respond to cages. In this study, we examine how hatchlings respond to self-releasing cages and use these data to assess if, on balance, cages are an effective management tool. Four questions were primary. (1) Do cages placed above nests at dark and illuminated sites affect orientation? (2) Do lights behind the beach cause hatchlings to be trapped within cages? (3) If trapping occurs, do subsequent changes in artificial and/or natural lighting eventually allow turtles to escape and if so, under what conditions?, and (4) Can darkening the cage interior at illuminated sites decrease trapping and promote seaward orientation?

METHODS—*Study sites*—Study areas at Boca Raton were chosen by conducting preliminary beach surveys and experiments at dark and artificially illuminated sites. During experiments, turtles were released in the center of a 4.0 m diameter, circular "arena" drawn in smoothed, leveled beach sand. After they crawled away from the arena center, orientation paths (measured from their flipper prints in the sand) were recorded. Each turtle's exit direction, relative to the arena center, was measured with a "data scope" flux-gate compass. Hatchlings that failed to immediately crawl (<5% of those tested) were excluded. "Dark" sites were those where hatchling orientation paths were normal (i.e., ±20° of a path straight toward the ocean). "Illuminated" sites were those where artificial lights were clearly visible from the beach, and where crawling paths of the turtles were circuitous.

Field measurements—Light levels near the horizon were measured using an Optec (SSP; 16° angle of acceptance) stellar photometer, mounted on a small tripod, and aimed for each measurement in the eight cardinal directions. These measurements were necessary because during orientation, hatchlings respond primarily to visual cues near the horizon (Witherington, 1992; Salmon et al., 1992). The Optec was calibrated (with a Licor LI-1800–02 Optical Radiation Calibrator) to provide an absolute measure of light intensity (in photons/s/cm^2) at 500 nm, which closely matched the maximum sensitivity to light (510 nm) of dark-adapted juvenile green turtles (Granda and O'Shea, 1972). We also measured the direction and intensity of any artificial light sources and, when the moon was present, its reflected light. Moon azimuth was measured with the data scope compass; moon altitude was determined using an inclinometer.

Hatchlings—Turtles were obtained from marked nests relocated within 24 h of deposition to on-the-beach hatcheries in Broward County, or from natural nests at Boca Raton. Nests were checked 45–50 days after deposition for signs of an impending emergence (a depression in the surface sand, just above the nest). From 12–24 hatchlings, ready to emerge that evening, were removed in the afternoon from at least two nests (without disturbing the remaining turtles). Captured hatchlings were placed in a lightproof styrofoam cooler containing damp sand to prevent dehydration, transported to a darkened laboratory room, and left undisturbed until they were taken to the beach that evening for testing. Turtles were used for one trial. Most were released on a dark beach that night but some, used in dawn experiments (see below), were held in the laboratory until the next dark period, then released.

Experiments—Five types of experiments were done. (1) We compared how accurately turtles located the ocean at two dark sites (Red Reef Park, South Beach Park) and at two illuminated condominium sites (Stratford Arms; 3000 South) when a cage was present or absent. We used the following procedures.

Turtles were released in the arena center in groups of three, under either the "cage" or "no cage" condition, until sample size (typically, 24 turtles/group) was achieved. A standard Boca Raton nest cage (0.6 m bottomless cube of 1.1 cm mesh on the sides, back and top, and 5.0 × 10.0 cm mesh on the front panel) was used. Cages were placed in the arena center, with the front panel parallel to the shoreline. Arenas in all experiments were placed in the same location each evening: a site centered between the dune and the high tide strand line (at the parks), or between the patio wall and the high tide strand line (at the condominiums). At Boca Raton, most females nested in this area. Trials were done over several evenings. Tests were paired so that trials at illuminated and dark sites were done on the same evening. Illuminated and dark sites were visited in reversed order during successive nights of testing.

Hatchlings at dark sites exited the cage and arena within 2 min. At illuminated sites, turtles inside cages after 5 min were designated as cage "trapped."

(2) At each site, we compared orientation when experiments were done under dark conditions (new moon), and when background light levels were naturally elevated by lunar illumination (±two days of the full moon).

(3) At two sites (the 3000 South condominium; a private residence 200 m to the south) we did experiments to determine when trapped turtles might escape from a cage. On four evenings, 12—24 hatchlings were released inside a cage exposed to high levels of artificial lighting. Their behavior was monitored for 2 h during "night" tests (starting at 2300 h in front of 3000 South), and for one h before sunrise at the residence during "pre-dawn" tests. We recorded: (i) the time when each turtle escaped from the cage, (ii) its crawling path and exit angle, (iii) any changes in lighting conditions (i.e., lights turned on or off; increase in natural light levels toward sunrise), and (iv) the number of hatchlings which failed to escape by the end of observations. During night tests, the Optec photometer was used to measure changes in artificial lighting; at dawn, relative increase in light radiance to the east was measured every 10 minutes, using an International (IL 1700) radiometer.

(4) On four evenings at 3000 South, the behavior of turtles trapped within a cage (7 groups; 2—8 turtles/group) was observed for 10 minutes, beginning immediately after they were released inside the cage. To measure where turtles were located, the interior of the cage was divided into four peripheral and one central zone. At one minute intervals, we recorded (i) the number of hatchlings located in each zone, and (ii) the number of crawling and non-crawling individuals.

(5) We determined if darkening the cage interior reduced the number of trapped turtles at illuminated sites, and improved seaward orientation. Experiments were done during new and full moon (two evenings each). The cage was darkened by attaching black plastic sheeting to the back and two side panels. In separate experiments, the sheeting extended from beach level

half-way to the top of the cage (a 50% barrier), and from beach level to the top of the cage (a 100% barrier). The east cage wall (facing the ocean) was not modified. Groups of three hatchlings were released under alternating "dark cage" and "open cage" conditions until sample size ($n = 22–24$ turtles/group) was achieved. Crawling paths and exit angles for each turtle that left the cage were recorded. Sheet elevation (35^0 for the 50%, 70^0 for the 100% group) was measured with an inclinometer from the central depression (where turtles were released).

Statistics—Exit angles recorded for each turtle in a single experiment were used to calculate a group mean angle and r-vector (dispersion; Zar, 1984). Rayleigh tests were used to determine if groups of turtles were significantly oriented. Watson two-sample non-parametric tests were used to determine if orientation differed among caged and uncaged, dark site and illuminated site, and dark cage and open cage, groups. Chi-square tests were employed to determine if proportions of trapped turtles differed among the groups.

RESULTS—*Orientation and behavior at dark sites*—At the two dark sites (Red Reef Park, Fig. 1; South Beach Park, Fig. 2), each group of hatchlings showed statistically significant seaward orientation (Rayleigh p values all <0.01). All turtles exited the arena within 1.5 min. There were no statistical differences between the cage and no-cage groups, either under new moon or under full moon conditions (Watson tests). There were also no statistical differences in group mean angle (after correction for minor differences in shoreline direction).

Orientation at the illuminated sites—At Stratford Arms under a new moon (Fig. 3), most hatchlings crawled on straight paths but in directions other than toward the ocean. When released within a cage, 11 of 24 turtles were trapped. Most (9) of the 13 turtles which escaped crawled toward the sea. Under a full moon (lower diagrams), both the no cage and caged groups showed accurate seaward orientation, and cage trapping was reduced. On one evening, these tests were done after a rain which made it impossible to discern the flipper prints (of 10 of the 21 turtles which left the cage). However, all exit angles were recorded. Group data (mean angle of 120°, r-vector = 0.89), and our observations during the tests, indicated that most turtles crawled SE instead of east toward the sea. The no cage and cage groups tested under a full moon showed no significant difference in group orientation ($U^2 = 0.0811$, $p > 0.10$).

At 3000 South artificial illumination was stronger (compare the shaded areas, Figs. 3 and 4). During new moon, most hatchlings in the absence of a cage crawled west toward the lights (Fig. 4; Rayleigh $z = 9.7749$, $p < 0.001$). Caged turtles also showed significant group orientation ($z = 5.0280$, $p < 0.002$), but to the SSW. Many (17 of 24) were trapped. Under a full moon, however, neither the uncaged nor the caged hatchlings showed significant group orientation (uncaged $z = 2.9036$, $p > 0.10$; caged $z = 1.6082$, $p > 0.20$), and the proportion of trapped turtles (5 of 23) was significantly reduced compared to the proportion observed during new moon ($X^2 = 11.695$, d.f. = 1, $p < 0.001$).

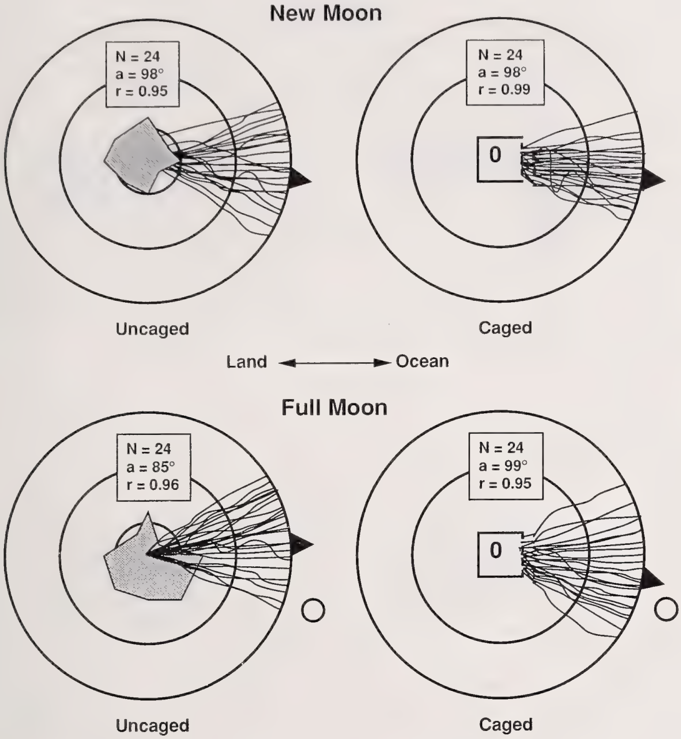


FIG. 1. Crawling paths (lines within circles) and orientation of hatchlings tested in arenas at Red Reef Park, a dark site. Top row: new moon experiments; bottom row, experiments done under full moon illumination. Diagrams to the left are tests done without a cage; those to the right, with a cage (box centered within the circle). Numbers within the boxes equal the number of cage-trapped turtles. Shaded area within left circles shows the light intensity measured in eight cardinal directions from the center of the arena. Inner, middle and outer circles in each diagram correspond to light intensities of 10^{10}, 10^{11}, and 10^{12} photons/s/cm^2, respectively, at 500 nm. Moon azimuth is indicated by the small circle outside the lower diagrams. Enclosed values are the sample size (N), mean angle (a, black triangle bordering each circle), and dispersion (r) for each group of turtles.

Escape of trapped turtles at night and at dawn—During night tests, 22 of 28 hatchlings (79 %) escaped from the cage (Fig. 5). Most hatchlings exited the cage intermittently, beginning after levels of artificial lighting declined by about 50% (by 2330 h). During dawn tests, 60 of 70 tested hatchlings (86%) escaped from the cage. Most escapes occurred during a short (30 min) interval, beginning about 45 minutes before sunrise. Crawling paths of turtles escaping at night were scattered and failed to show significant group orientation (Fig. 6; $z = 2.0361$, $p > 0.10$) whereas most turtles escaping at dawn crawled directly toward the sea ($z = 42.2785$, $p < 0.001$).

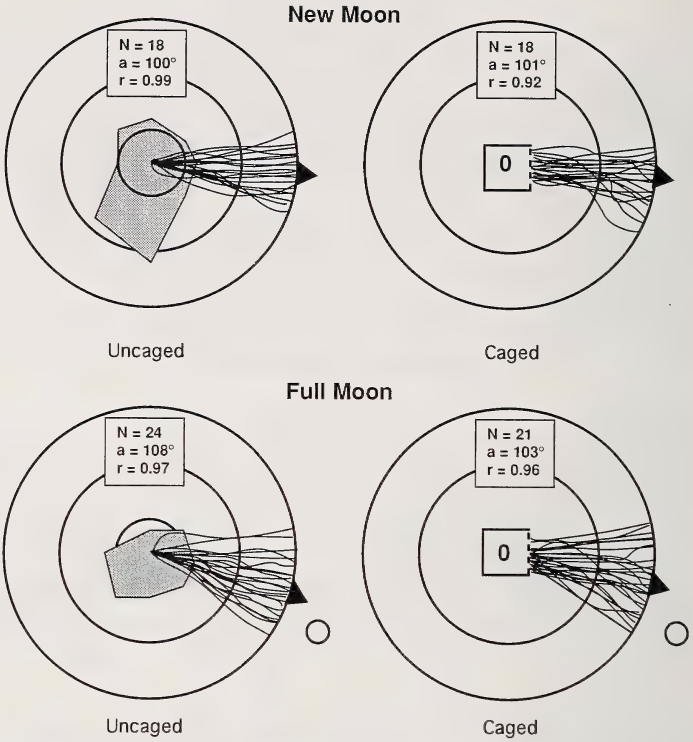


FIG. 2. Crawling paths and orientation of hatchlings tested South Beach, another dark site. Format, as in Figure 1.

Behavior of cage-trapped turtles—Most (88%) of the trapped turtles (n = 35) crawled against the landward side of the cage (zones 2 and 3, Fig. 7). The number of crawling hatchlings declined during observations from 83% (end of minute one) to 28% (end of minute 10; Fig. 7).

Darkening the cage—Under new moon conditions (Fig. 8), 15 of 21 turtles (71%) were trapped in the open cage. Trapping was eliminated when dark plastic was attached to the cage walls. Turtles leaving the open cage failed to show significant group orientation ($z = 1.2666$, $p > 0.20$) whereas hatchlings leaving darkened cages did ($z = 9.2439$ for the 50% barrier group; $z = 7.7372$ for 100% barrier group; $p < 0.001$ for both groups). Most hatchlings exiting from darkened cages crawled southeast instead of east (toward the ocean).

Under full moon illumination (Fig. 9), fewer (2 of 20) turtles were trapped inside the open cage. Trapping was also eliminated by a 50% or 100% barrier. Hatchlings exiting the open cage ($z = 6.6978$), as well as those exiting darkened cages ($z = 7.2128$ for the 50%; $z = 7.5264$ for the

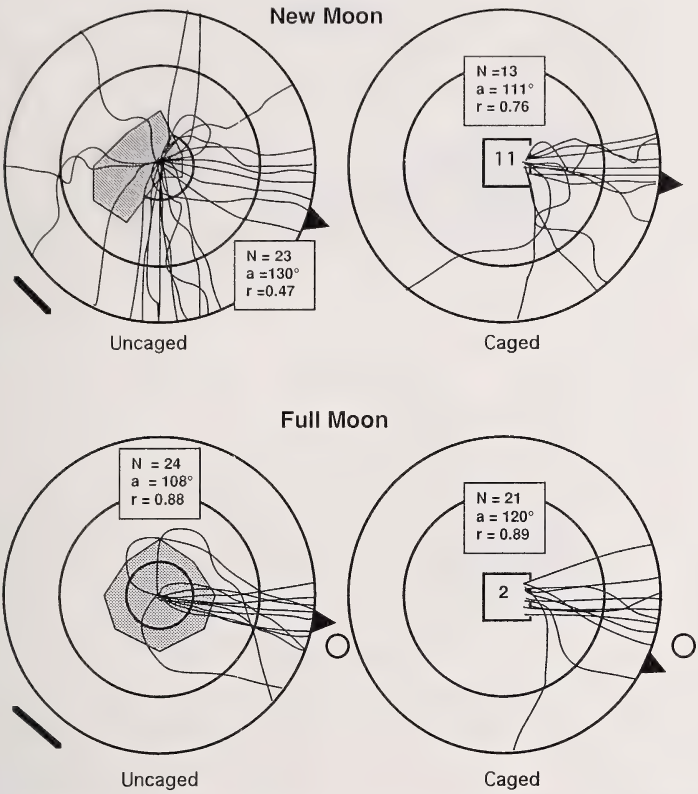


FIG. 3. Crawling paths and orientation of hatchlings at Strafford Arms, an illuminated site. Thick line outside the left diagrams represents the direction toward the brightest light source that evening. Format in all other respects, as in Figure 1.

100 % group), showed significant group orientation ($p < 0.001$ for all groups). However, most turtles again crawled southeast instead of east.

DISCUSSION—*Cage effects at dark and illuminated sites*—At the park sites no turtles were trapped in the cages, nor was hatchling orientation influenced by a cage on either moonless or full moon evenings. These data suggest that at these dark sites, cages are not used as a visual stimulus (elevated cue: Mrosovsky, 1970; form vision cue: van Rhijn, 1979; Witherington, 1992), nor do they interfere with the detection of other cues required for normal seafinding.

At our condominium sites, especially during new moon, many hatchlings tested without a cage showed disturbed orientation behavior. Disturbance was manifested by either disorientation (turtles crawl in different directions) or misorientation (turtles crawl in a similar direction, but not towards the ocean; Verheijen, 1958). Cages at these sites did not appear to alter the orientation of those turtles which left the cage, as their group mean angles

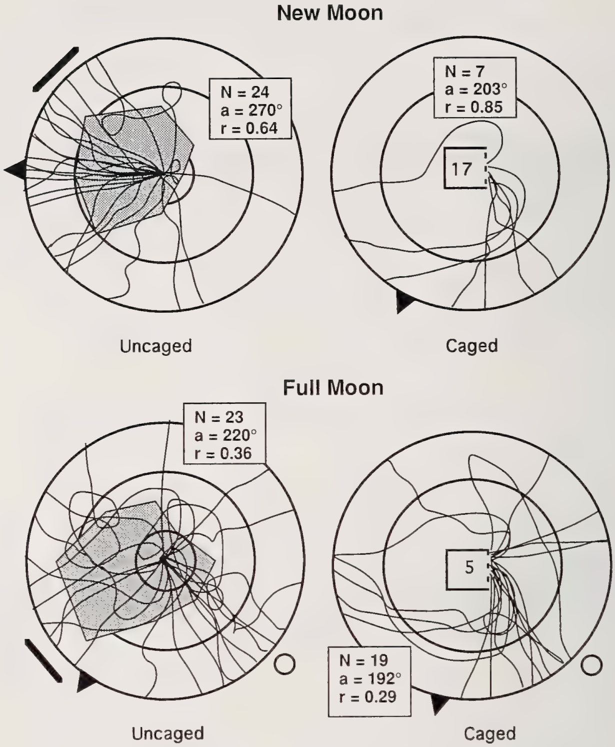


FIG. 4. Crawling paths and orientation of hatchlings at 3000 South, another illuminated site. Format, as in Figure 1.

and paths were usually similar to those shown by uncaged turtles. Cages at illuminated sites did, however, act as a physical barrier which trapped many turtles.

Factors affecting the severity of cage trapping—The relative proportion of hatchlings which became trapped was correlated with two factors: the intensity of artificial lighting and the level of natural background (lunar or solar) illumination. These two variables are considered separately.

When artificial light intensity was relatively low (Stratford Arms), uncaged turtles on dark evenings were disoriented. These turtles could detect cues required to crawl on straight paths, but were unable to determine a preferred group direction. The cage may have acted like a "filter" which allowed only those turtles, which by chance crawled toward the large-mesh wall, to escape. At 3000 South where artificial lighting was more intense, uncaged hatchlings on dark nights showed misorientation, i.e., they were attracted toward the lights. A greater proportion of the caged turtles should be trapped as their westward orientation would bring them into direct contact with the fine mesh cage walls from which escape was impossible. Our results

Allen Press, Inc., Lawrence, KS 66044 USA

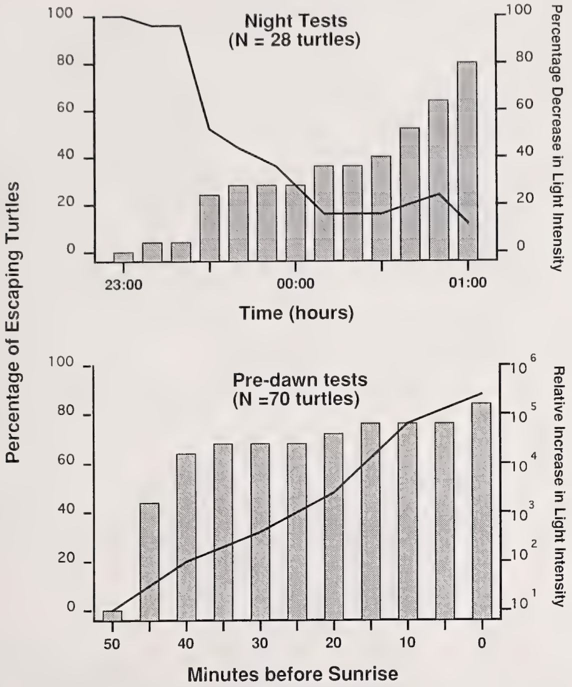


FIG. 5. The cumulative percentage of turtles that escaped from the cage (vertical shaded bars), as a function of time after the start of the experiments at night (above), and at dawn (below). Ascending (top) and descending (bottom) thin lines within graphs show changes in light intensity over the time of observations.

were consistent with that hypothesis. They also confirm that at high intensities, artificial lighting acts as a strong ("supernormal") orientation stimulus (Witherington, 1997).

While lunar illumination had no influence on orientation behavior at the parks, at illuminated sites it reduced cage trapping and affected hatchling

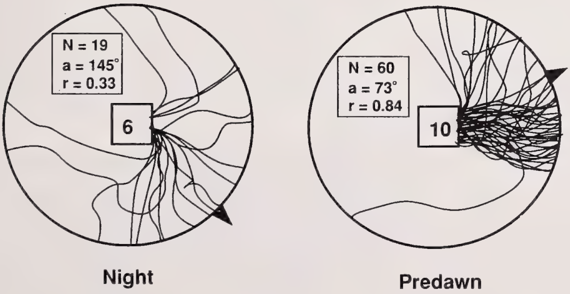


FIG. 6. Orientation paths of turtles as they escaped from the cage in the night and predawn experiments.

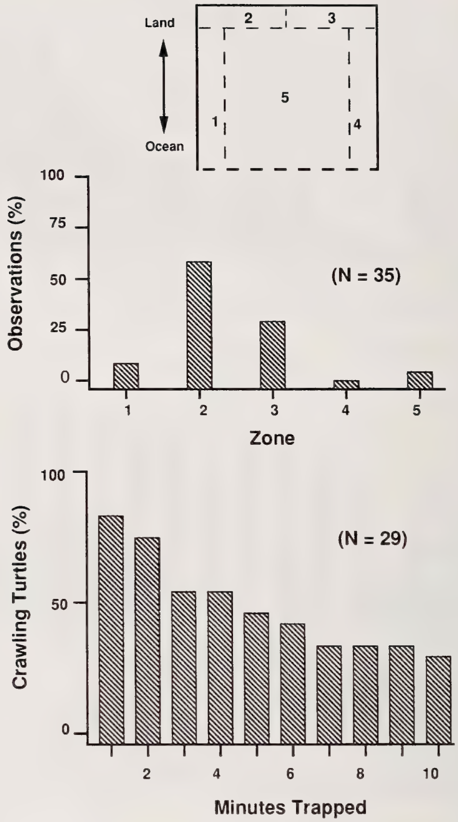


FIG. 7. Above, cage zones. Middle, cumulative distribution of trapped turtles (N = 35) in cage zones, observed and then summed for every minute for 10 minutes. Bottom, percentage of 29 turtes which continued to crawl inside a cage over 10 minutes of observations.

orientation. At Stratford Arms, seafinding accuracy of uncaged turtles improved so that during a full moon, turtles could locate the sea. Most caged turtles also crawled east and left the cage . At 3000 South moonlight reduced the attraction of turtles to artificial lighting, compared to their response during new moon. Cage trapping was also reduced. But even under a full moon, artificial lighting at 3000 South still attracted some caged turtles and prevented them from escaping. Lighting also prevented those which did escape from crawling toward the sea.

Verheijen (1958, 1985) proposed that artificial lights interfered with normal visual perception by producing "anisotropic" light fields: those in which light intensity in one direction (toward artificial lighting) greatly exceeded intensities in other directions. An increase in lunar (or solar) illumination probably reduces anisotropy by decreasing contrast between artificial light sources and background light levels. Bright moonlight also is correlated with a reduction in the reported cases abnormal orientation by sea turtle hatch-

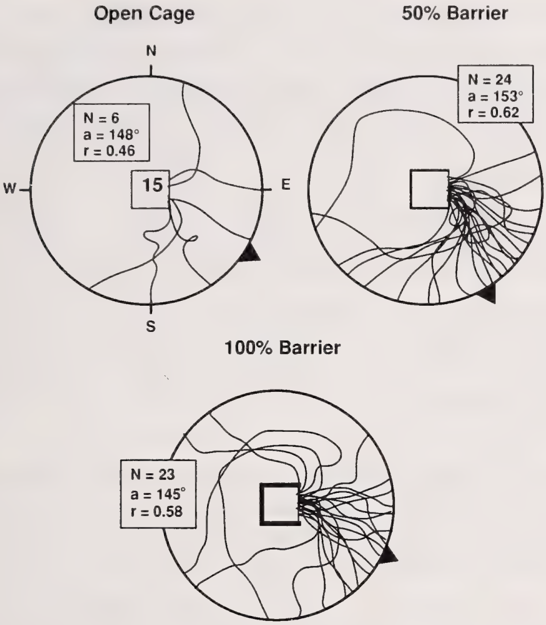


FIG. 8. Crawling paths and hatchling orientation at 3000 south during new moon after turtles exited an unaltered cage, a cage with a 50% black plastic barrier, and a cage with a 100% black plastic barrier attached to the rear wall and sides. Format, as in Figure 3.

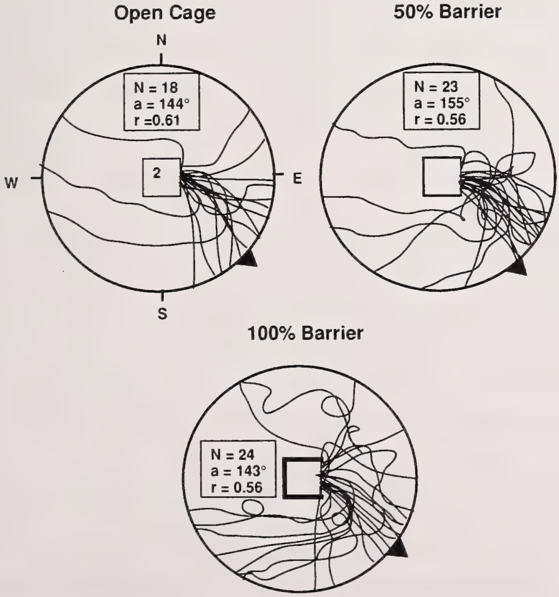


FIG. 9. Crawling paths and hatchling orientation at 3000 South during a full moon after turtles exited an unaltered cage, a cage with a 50% barrier, and a cage with a 100% barrier.

lings on Florida beaches (Salmon and Witherington, 1995), as well as the severity of related effects among insects, birds, and other nocturnally active organisms (Verheijen, 1981). Our results also show that when artificial lighting is intense (3000 South), even full moon illumination may be insufficient to reduce anisotropy so that all of these effects are eliminated (Salmon and Witherington, 1995).

Trapping was eliminated by adding a black backing to the cage. This alteration shielded turtles from light and probably created a strong photic contrast between the darker cage walls and the seaward horizon. Photic cues can be used by hatchlings to locate the sea (Limpus, 1971; Mrosovsky and Kingsmill, 1985; Salmon et al., 1992). Once hatchlings left the cage and were subsequently exposed to artificial lighting, artificial lighting still affected their performance.

Consequences of cage trapping—Since artificial lighting interferes with seafinding at several locations on Boca Raton's beach (Salmon et al., 1995b), and since all nests are caged by the city, it is likely that cage trapping occurs elsewhere on the beach. But city workers rarely find any trapped turtles when they do their morning surveys. Our data suggest that trapped turtles eventually escape from the cage, either as lights in the city or within apartments are turned off (toward midnight) or as background illumination increases (toward sunrise).

Escape does not necessarily promote hatchling survival. When hatchlings left cages at night, their orientation could still be disrupted by artificial lighting. Where beach-front lighting is more intense, hatchlings might remain trapped until dawn. While most turtles then showed seaward orientation, they are exposed to visual predators (birds and fishes; Limpus, 1973; Stancyk, 1982) on land or in shallow water near shore. Turtles normally avoid these risks by emerging from nests at night (Witherington et al., 1990).

Trapped turtles waste time and energy crawling within the cage; most eventually ceased movement. Hatchlings may have stopped crawling due to elevated lactate levels (Dial, 1987; Baldwin et al., 1989), muscle fatigue, and exhaustion (Bennett and Licht, 1972). Turtles normally complete a rapid ($\leq$2 min) crawl from the nest to the ocean, then swim offshore. During this time, hatchlings are in their "frenzy" state (Carr, 1962) and can swim continuously for about 24 h (Wyneken and Salmon, 1992). But our observations suggest that continued locomotion on land quickly exhausts a small turtle.

Benefits and costs of caging—Cages were originally used at Boca Raton to protect nests from foot traffic and from mammalian predators. In South Florida, raccoons are the most serious threat. On some beaches in the southeastern U.S., these animals can destroy up to 96% of the local nests (Stancyk, 1982). "Screening" nests (covering them with a sheet of wire mesh, placed just below the sand surface) is another method of protection

(McMurtray, 1986). This procedure is not used at Boca Raton because buried screens might injure beach visitors.

In 1995, about 8% of the caged nests at Boca Raton were attacked by mammalian predators (mostly raccoons; some spotted skunks and foxes). Although the specific circumstances leading to predation were not recorded, the general circumstances were. Some nests were taken during the evening they were deposited, i.e., before they could be protected by a cage. Cages used up to 1994 were less effective than those used now. Older cages were identical in size and shape to those in current use, but constructed entirely of small mesh. One corner of the cage, on the ocean-facing side, was opened a few days before an anticipated emergence to allow the hatchlings to escape. But raccoons were able to overturn some of these cages, presumably by levering them off the sand at that corner. Self-release cages with larger mesh on one side eliminate that problem. They are also buried more deeply (and securely) in the sand. Without cages, predation rates at Boca Raton would be higher, especially at the parks where raccoons are abundant. But since all nests are covered with a cage, it is impossible to estimate how much protection is actually afforded, or even if cages are needed to protect nests on the entire beach.

In addition to protecting nests, cages have other benefits. They alert residents and visitors to each nest's location, are convenient platforms for signs which warn against egg poaching or disturbance, are less likely than underground screens to cause beachgoer injury, and contribute to public awareness of current conservation efforts. Cages are also convenient markers for city workers, who must locate (and excavate) nests to determine nesting "success" (proportion of emerging hatchlings relative to the clutch size). Cages thus provide a convenient solution to many management problems on urban beaches. Alternatives (such as marking nests with stakes) were tried, and deemed inferior at Boca Raton. Many stakes were removed, in spite of their warning signs, while others were moved so that locating nests was difficult.

This study reveals that cages have several costs, all of which occur as a consequence of exposure of the beach to artificial lighting. These include: (i) trapping, with associated energy loss as hatchlings attempt to escape; (ii) a failure to prevent orientation disruption; and (iii) delay of migration, sometimes until dawn when hatchlings might be more vulnerable to high beach temperatures and to visual predators.

There are also likely, but undemonstrated, effects. Hatchlings which spend time trapped within a cage might be physiologically compromised by dehydration and stress. Turtles might also be more vulnerable to predators because they enter the sea as individuals instead of as a group, and can not benefit from "predator swamping" effects (Bustard, 1972).

Caging is unsatisfactory from a management perspective for two other reasons. First, cages obscure beach lighting problems. Caged nests exposed to the brightest lights are those most likely to entrap turtles for the entire dark period. When these hatchlings escape at dawn, their tracks will be difficult to distinguish from those of turtles orienting normally on dark beaches. Unless direct observations are made, these tracks will create the false impression that no lighting problem exists. Secondly, cage use consumes resources (costs of wire, cage fabrication, deployment, removal, and repair) which might be more effectively used to correct lighting problems.

Caging on illuminated beaches therefore exemplifies "half-way technology" (Frazer, 1992), that is, a management strategy which treats symptoms rather than causes of an environmental problem. Our results suggest that it is only on dark beaches that cages effectively protect nests from foot traffic and predators. Thus on urban beaches where lighting problems are common, caging is effective only if coupled with a campaign to reduce or eliminate beach lighting. Fortunately, a number of effective procedures are known (Raymond, 1984); unfortunately, the severity of the problem at sea turtle rookeries is not generally appreciated (Witherington, 1997). If greater efforts are made to reduce photopollution in South Florida, the result should be a significant improvement in sea turtle reproductive success at Boca Raton, and at many other urban beaches.

ACKNOWLEDGMENTS—This study was completed by S.L.A. in partial fulfillment of the requirements for a masters degree in biology at Florida Atlantic University. Support was provided by funds from the Boca Raton Garden Club, and work was expedited by personnel at the Gumbo Limbo Nature Complex. We thank A. Marsh for comments on an earlier draft, and M. Goff for assistance in the field. This research was permitted by the Florida Department of Environmental Protection (TP-073).

LITERATURE CITED

BALDWIN, J., E. GYURIS, K. MORTIMER, AND A. PATAK. 1989. Anaerobic metabolism during dispersal of green and loggerhead turtle hatchlings. Comp. Biochem. Physiol. 94A: 663–665.

BENNETT, A. F. AND P. LICHT. 1972. Anaerobic metabolism during activity in lizards. J. Comp. Physiol. 81: 277–288.

BUSTARD, H. R. 1972. Sea Turtles: Natural History and Conservation. Taplinger Publishing Company. New York, NY.

CARR, A. 1962. Orientation problems in the high seas travel and terrestrial movements of marine turtles. Amer. Sci. 50: 359–374.

DIAL, B. E. 1987. Energetics and performance during nest emergence and the hatchling frenzy in loggerhead sea turtles (*Caretta caretta*). Herpetologica 43: 307–315.

EHRHART, L. M. 1989. Status report on the loggerhead turtle. Pp. 122–144. *In:* OGREN, L. (ed.), Proc. Second Western Atlantic Turtle Symposium, NOAA Technical Memorandum NMFS-SEFC-226.

FRAZER, N. B. 1992. Sea turtle conservation and halfway technology. Conserv. Biol. 6:179–184.

GRANDA, A. M. AND P. J. O'SHEA. 1972. Spectral sensitivity of the green turtle (*Chelonia mydas mydas*) determined by electrical responses to heterochromatic light. Brain Behav. Evol. 5:143–154.

LIMPUS, C. J. 1971. Sea turtle ocean finding behaviour. Search 2:385–387.

———. 1973. Avian predators of sea turtles in south-east Queensland rookeries. Sunbird 4: 45–51.

MAGNUSON, J., K. A. BJORNDAL, W. D. DUPAUL, G. L. GRAHAM, D. W. OWENS, C. H. PRICHARD, J. I. RICHARDSON, G. E. SAUL AND C. W. WEST. 1990. The Decline of Sea Turtles: Causes and Preventions. National Academy Press, Washington. D.C.

MCMURTRAY, J. 1986. Reduction of raccoon predation on sea turtles nests at Canaveral National Seashore, Florida. Masters Thesis, University of Georgia, Athens, GA.

MEYLAN, A., B. SCHROEDER, AND A. MOSIER. 1995. Sea turtle nesting activity in the state of Florida. Florida Marine Research Publications, 52.

MROSOVSKY, N. 1968. Nocturnal emergence of hatchling sea turtles-. control by thermal inhibition of activity. Nature 220: 1338–1339.

———. 1970. The influence of the sun's position and elevated cues on the orientation of hatching sea turtles. Anim. Behav. 18: 648–651.

——— AND S. F. KINGSMILL. 1985. How turtles find the sea. Z. Tierpsychol. 67: 237–256.

RAYMOND, P. W. 1984. Sea turtle hatchling disorientation and artificial beachfront lighting: A review of the problem and potential solutions. The Center for Environmental Education and Sea Turtle Rescue Fund, Washington, D.C.

SALMON, M., J. WYNEKEN, E. FRITZ, AND M. LUCAS. 1992. Seafinding by hatchling sea turtles: role of brightness, silhouette and beach slope as orientation cues. Behaviour 122: 56–77.

———, R. REINERS, C. LAVIN, AND J. WYNEKEN. 1995a. Behavior of loggerhead sea turtles on an urban beach. I. Correlates of nest placement. J. Herpetol. 29 (4): 560–567.

———, M. G. TOLBERT, D. P. PAINTER, M. GOFF, AND R. REINERS. 1995b. Behavior of loggerhead sea turtles on an urban beach. II. Hatchling orientation. J. Herpetol. 29 (4) : 568–576.

——— AND B. E. WITHERINGTON. 1995. Artificial lighting and seafinding by loggerhead hatchlings: Evidence for lunar modulation. Copeia. 1995: 931–938.

STANCYK, S. E. 1982. Non-human predators of sea turtles and their control, Pp 139–152. *In*: BJORNDAL, K. A. (ed.), Biology and Conservation of Sea Turtles. Smithsonian Institution Press, Washington, D.C.

VAN RHIJN, F. A. 1979. Optic orientation in hatchlings of the sea turtle *Chelonia mydas*. 1. Brightness: not the only optic cue in sea-finding orientation. Mar. Behav. Physiol. 6: 243–255.

VERHEIJEN, F. J. 1958. The mechanisms of the trapping effect of artificial light sources upon animals. Arch. Neerl. Zool. 13:1–107.

———. 1981. Bird kills at lighted man-made structures: not on nights close to full moon. Am. Birds 35: 251–254.

———. 1985. Photopollution: artificial light optic spatial control systems fail to cope with. Incidents, causation, remedies. Exp. Biol. 44:1–18.

WITHERINGTON, B. E. 1992. Sea-finding behavior and the use of photic orientation cues by hatchlings sea turtles. Ph. D. dissertation, University of Florida, Gainesville, FL.

———. 1997. Biological photopollution and the problem of artificial lighting on sea turtle nesting beaches. Pp. 303–327. *In:* CLEMMONS, J. R. AND R. BUCHHOLZ (eds.) Behavioral Approaches to Conservation in the Wild, Cambridge University Press, NY.

———, K. BJORNDAL, AND C. M. MCCABE. 1990. Temporal pattern of nocturnal emergence of loggerhead turtle hatchlings from natural nests. Copeia 1990:1165–1168.

WYNEKEN, J. AND M. SALMON. 1992. Frenzy and post-frenzy swimming activity in loggerhead, green turtle and leatherback hatchling sea turtles. Copeia 1992: 478–484.

ZAR, J. H. 1984. Biostatistical Analysis. Prentice Hall, Englewood Cliffs, NJ.

Florida Scient. 60(4): 239–253. 1997
Accepted: May 6, 1997.

COASTAL CURRENTS INDUCED BY HURRICANE ANDREW

WILLIAM MCLEISH(1), DONALD V. HANSEN(2) AND JOHN R. PRONI(1)

(1)NOAA/Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida 33149
(2)University of Miami/Cooperative Institute for Marine and Atmospheric Studies,
Miami, Florida 33149

ABSTRACT: *Ocean current meters in 18 and 24 m depth water along the southeast Florida coast recorded water motions as Hurricane Andrew crossed the narrow continental shelf with the storm center 32 km from the southernmost current meter. Wind speeds up to 55 m* s^{-1} *at the meter closest to the storm path were associated with recorded mean current speeds up to 94 cm* s^{-1}*. The greatest water speeds, however, were transient motions from the wind waves. These motions caused major changes to the bottom and to objects lying on it. Direct and remotely sensed observations showed an increasing degree of turbulence in the water as the hurricane approached, stirring both air bubbles and bottom sediment throughout the water and mixing the water so that vertical shear in the current was suppressed. Thus, beneath the strong wind stress there was not a mean water flow in the direction of the wind at the surface and a flow in the opposite direction near the bottom, as had been indicated in previous studies. In later stages of the storm passage, the current developed an eastward component, running against the incoming wind waves, which may have contributed to the evolution of the most extreme conditions.*

HURRICANE Andrew, the most costly natural disaster ever to strike the United States, crossed the coast of southeast Florida in the early morning hours of August 24, 1992 (Mayfield and Avila, 1993, p. 22). Although landfall occurred close to the time of astronomical high tide, and a storm surge in excess of 5 m was experienced, structural damage at the shorefront was not as extensive as it might have been because the strongest part of the storm impinged upon a mostly sparsely developed mangrove coast. The coastal vegetation and built-up hinterland were savaged by the fury of the winds (Wakimoto and Black, 1994). Tilman and co-workers (1994), Fong and Lirman (1994), and Lirman and Fong (1996) describe underwater effects of Andrew on the coastal reefs, embayments, and marine life. The offshore reefs, in general, suffered only modest and patchy damage that included some overturning and breaking of coral structures, channel scouring most evidently by southward-flowing currents, and smothering of organisms by relocated sediments. Artificial reefs in the form of sunken steel ships and barges at several sites along the coast were extremely damaged (Mostkoff, 1993). It has been hypothesized that damage to natural reef structures was not as great as has been wreaked by other hurricanes because, although it contained winds of exceptional speed, Andrew was relatively small and fast moving, so its intensity was felt for only a few hours.

Studies of hurricane effects on shallow water have been summarized by Halper and Schroeder (1990). They included cases where the hurricane eye was more than 230 km from instrument sites and where the hurricane effects on the water at the measurement location were minor. Smith (1982) found upwelling from a storm whose effect was detected for about 12 days and a decoupling of the surface flow from that below. Halper and Schroeder (1990) discussed destruction of the thermocline by a hurricane, presumably through vertical mixing. Murray (1970) reported offshore bottom currents which were suggested to have resulted from a two-layer flow in which the surface water moved onshore in the wind direction and the bottom flow moved offshore as a relaxation of a seaward pressure gradient developed by the wind. Snedden and co-workers (1988) discussed a three-layer flow that could result from major storms.

As Andrew approached the coast of Florida, we had in operation several current meters in the coastal waters. These installations were mostly destroyed during the rapid passage of this very strong hurricane, but some data were recorded until the time of destruction and recovered. This note is presented to describe these rare measurements and some related calculations and simulations. A general plan of the subject area is shown in Fig. 1. The southeast coast of Florida is characterized by a fringing reef flat of generally less than 10 m depth and 2–8 km width. Seaward of the 10 m depth contour, the depth increases rapidly to more than 800 m in the Straits of Florida. Biscayne Bay generally has depths of less than 4 m, and is separated from the Straits by a line of small islands and barely submerged reefs not shown on Fig. 1. Wastewater outfalls are located in about 28 m depth at the locations labeled DN and DC. Current meter moorings using Aanderaa current meters (Aanderaa Instruments, 1979) mounted at two levels, 12 m and 16 m beneath the ocean's surface, were operated in depths of 24 m, 0.25 km south of each of these sites to document the local current variations. A bottom-mounted acoustic Doppler current profiler (ADCP) was also in operation at 18 m depth, 65 m distant from the Aanderaa mooring near the DC site. As the center of Andrew moved westward across the coast, the eyewall containing the strongest winds passed south of the current meters as indicated in Fig. 1.

OBSERVATIONS AND ESTIMATIONS—*Surface wind and derived products*—Powell and Houston (1996) compiled all available wind observations from the south Florida area during Hurricane Andrew. Their analyses indicate that the probable maximum 1-minute average wind speed at site DC was 50–55 m s^{-1}, and at DN was on the order of 40 m s^{-1}, while the maximum storm winds (1-minute average greater than 65 m s^{-1}) occurred only 10–15 km south of site DC. A time series of vector winds at site DC (Figure 2, top panel) was synthesized from these analyses. The Waterways Experiment Station (WES) numerical wave model was used to calculate wind wave properties at a number of locations for each hour based on analyses of Hurricane Andrew (Tracy, 1993). Table 1 shows the dominant wave height, period, and direction

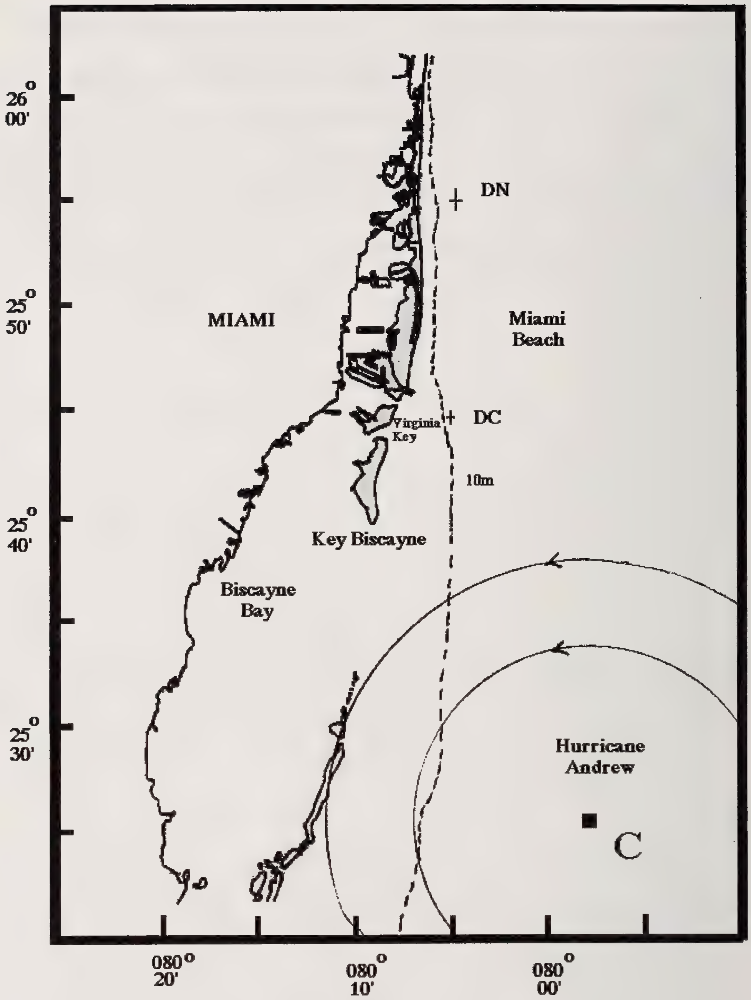


FIG. 1. Area of current measurements in Straits of Florida near Miami and location of Hurricane Andrew at 0400 EDT on August 24, 1992. Outfall locations shown are DC (Dade Central) and DN (Dade North). The dashed line is at 10-m water depth. Partial circles denote the hurricane eyewall and C is the center.

at site DC given by the WES model. Average and maximum wave orbital speeds at the depth of the Aanderaa current meter were calculated from the wave parameters using the Stokes second order equation. The second order term in this equation turned out to be negligible, however.

A numerical storm surge model (Jelesnianski et al., 1992) was used to hindcast the storm surge associated with Hurricane Andrew. Figure 3 shows the surge hindcast for several locations. The primary surge peak occurred near 0430, about when the center of the hurricane passed. The amplitude of the surge diminished with distance from the center of the storm. A surge in excess of 5 m was experienced on the western shore of southern Biscayne Bay. This is the storm surge induced by the strong westward wind and low atmospheric pressure. Figure

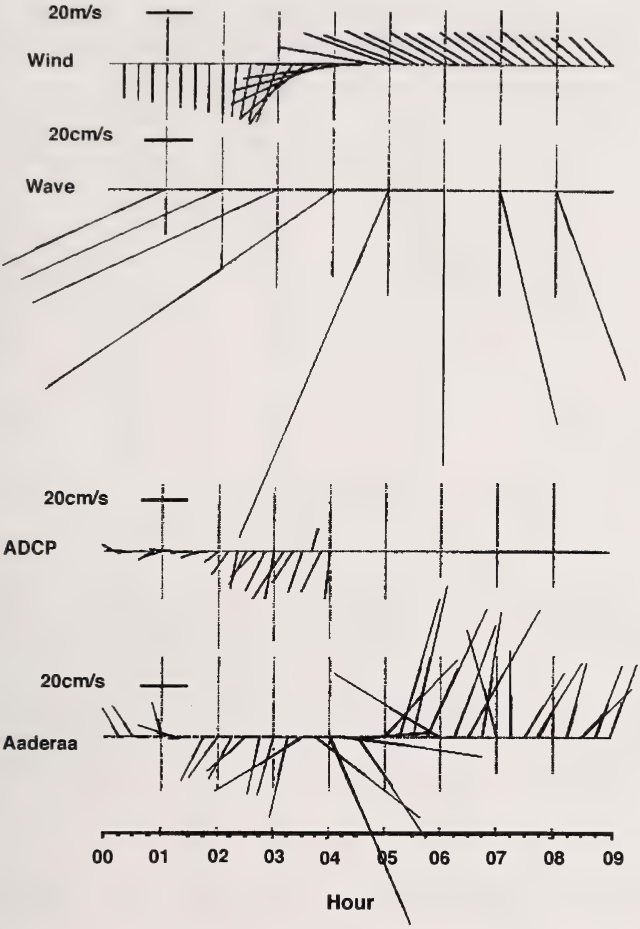


FIG. 2. Stick plots of analyzed wind, wave model product, and 16 m depth ocean current meter (ADCP and Aanderaa at DC) measurements at successive times. Upward stick direction is north, right is east, etc. Wind stick directions are directions toward which the air is moving. Wave stick directions are directions of propagation of the dominant waves, and stick lengths are average orbital speeds of the dominant waves. Water currents flow in the direction of the sticks. ADCP speeds are vector-averaged speeds, and Aanderaa speeds are average total speeds.

3 shows a second sea level maximum, nearly equal in amplitude to the first, near 0600 with the greatest value at Key Biscayne and directly onshore from site DC. The second peak has been attributed to reflection of the large surge farther south in Biscayne Bay, northward and eastward (Wiggert, 1993).

Current measurements—One Aanderaa current meter at 16 m depth on the mooring near site DC operated throughout the duration of the hurricane passage (Fig. 2); the second current meter at the 12 m depth had failed prior to the onset of Hurricane Andrew. The current recorded at this site was initially northward, then turned southward and increased to about 80 cm s^{-1} as the local wind speed grew to 40 m s^{-1}. With passage of the center of the hurricane, the current turned through east to north-northeast and slowly attenuated during the next few hours. The

TABLE 1. Wave orbital characeristics from Hurricane Andrew at location DC on August 23–24 at 16-m depth in 24-m water depth. Speed values calculated from Stokes second-order wave equation.

Hour (EDT)	Height (m)	Period (s)	Direction (degrees)	Average Speed ($cm\ s^{-1}$)	Maximum Speed ($cm\ s^{-1}$)
9 p.m.	4.9	10.0	244	72.4	117.7
10 p.m.	5.2	10.0	244	76.8	125.1
11 p.m.	5.6	10.0	245	82.8	135.1
12 p.m.	6.1	10.0	246	90.2	147.7
1 a.m.	6.7	11.1	245	106.2	178.3
2 a.m.	7.7	11.1	244	122.2	207.0
3 a.m.	9.3	12.5	243	157.7	281.0
4 a.m.	11.7	12.5	233	199.5	365.1
5 a.m.	11.4	12.5	202	194.3	354.4
6 a.m.	8.8	12.5	180	149.0	264.1
7 a.m.	7.4	12.5	167	125.0	217.8
8 a.m.	6.4	11.1	160	101.4	169.9

maximum (15 minute) average current recorded at this site was 94 cm s^{-1}, but it is likely that the Aanderaa meters over-registered speed in these very rough and turbulent conditions. Figure 4 shows the relationships between the north (alongshore) and east (offshore) vector components of the local surface wind and the measured current as they changed with time. The direction of the alongshore current corresponded closely to that of the wind, with a lag of less than 30 minutes as the center of the storm passed to the south. Especially during the time of maximum easterly wind and continuing during several subsequent hours when the wind had an easterly component, the current at 16 m depth was eastward. No more than 5 cm s^{-1} of this eastward flow can be attributed to the astronomic tide at any time (Lee and Mayer, 1977, Table 4).

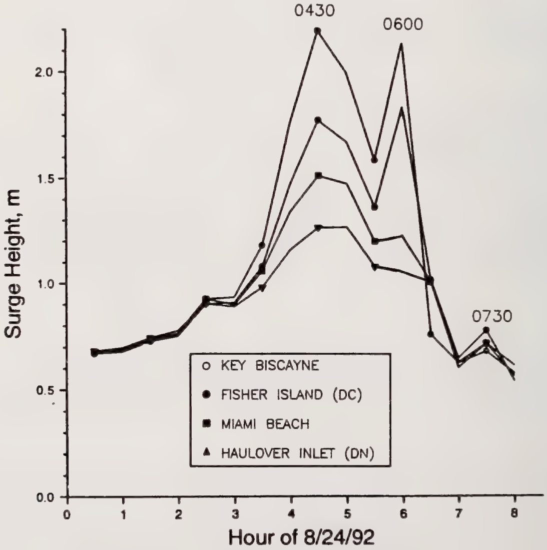


FIG. 3. Height of storm surge at four locations offshore versus time from numerical model. Key Biscayne site is 5 km south of DC.

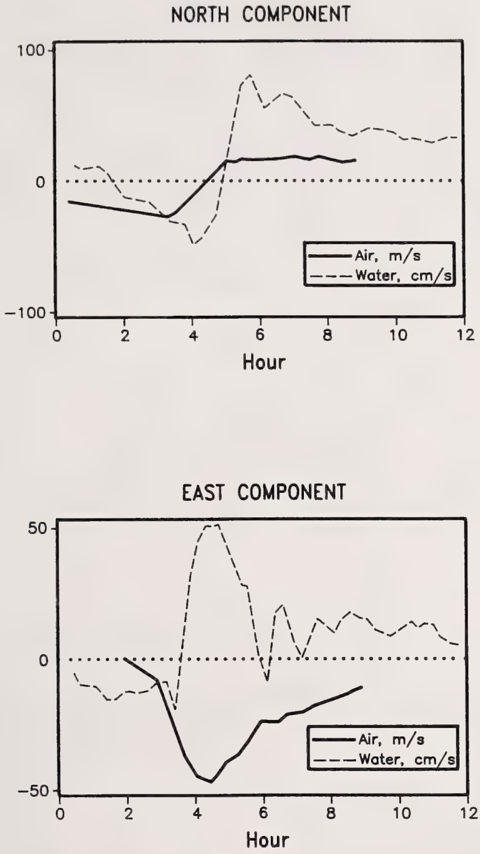


FIG. 4. Air and water velocity components at DC during hurricane passage from wind analysis and 16-m depth Aanderaa measurements 0000 to 1200 hours on August 24, 1992.

The Aanderaa current meter recovered from site DN operated until 0400, when it lost its speed sensor. Thereafter, it recorded only the direction of flow. The 16 m depth current at this location was predominantly northward, with a brief period of southward flow during about 0300 and 0500, and a brief period of eastward flow (of unknown magnitude) between about 0400 and 0430.

The currents recorded by the ADCP at 16 m depth 65 m west of the site DC mooring were initially to the west at 10 cm s^{-1} or less, then turned southward and accelerated as the center of the storm approached the coast (Fig. 2). The strongest 10-minute average current recorded before the array was overturned was only about 25 cm s^{-1}, or about one-third that recorded for a 15-minute average at the nearby Aanderaa current meter mooring. With the ADCP, orthogonal vector current components are measured separately at 0.5 Hz whereas the Aanderaa current meter assembly is nearly 2 m in length, and must be physically reoriented, requiring at least several seconds, to record changes of current direction. The ADCP is, therefore, generally accepted as providing much higher quality current measurements in the presence of strong high frequency variability such as large waves and high levels of turbulent energy. Figure 5 shows in hodograph format the vertical structure of currents measured by the ADCP at two-hour intervals as the storm approached. During the evening preceding Andrew, current near the bottom was toward the southeast at less than 10 cm s^{-1}, but strongly sheared to nearly

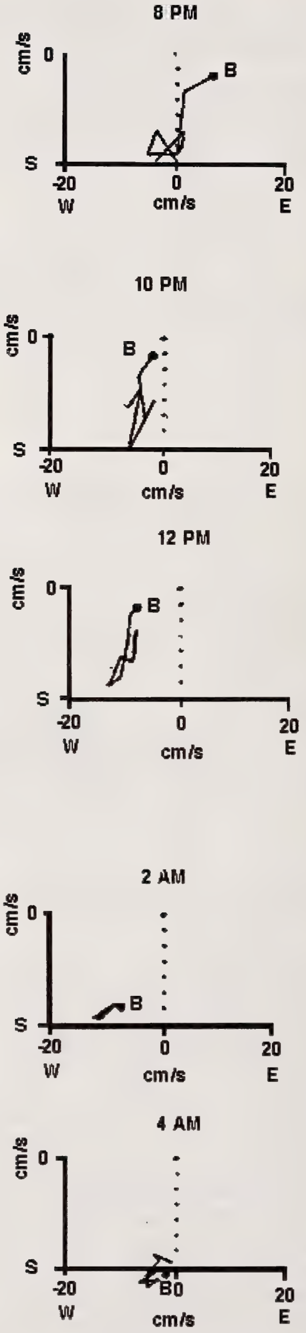


FIG. 5. ADCP current velocities at different depths, 1-hour average at 2-hour intervals from 8 p.m. on August 23, 1992 to 0400 on August 24, 1992 when the hurricane passed. The 0400 plot represents a single 10-minute set of readings. Positive current components are to the north and the east. Each plot shows the currents from 16 m depth (B) to 5 m depth at 1 m intervals.

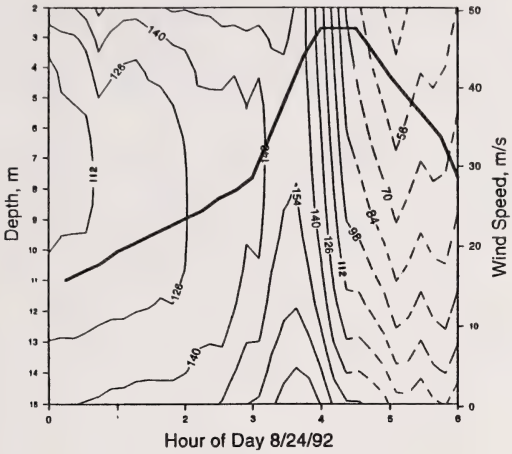


FIG. 6. Amplitudes in decibels of ADCP acoustic pulses returned from different depths at DC during hurricane approach and passage. The instrument was overturned at about 0430 and later acoustic readings (dashed lines) are not valid. The thick line is wind speed.

20 cm s^{-1}, southward in the shallower levels. As the storm approached, the current became increasingly uniform with depth although still about 20 cm s^{-1}.

Suspended sediment and turbulence—Figure 6 shows the evolution in time of the returned acoustic pulse amplitudes received at the ADCP. Prior to the starting time for the plot, most pulse amplitudes were near 100 dB, typical of clear Florida Current water. As wind speed increased in the early morning hours of August 24, pulse amplitudes near the surface and near the bottom became 20–30 dB greater than in the middle depths. After the storm became severe (0330–0345), pulse amplitudes at all depths decreased rapidly, soon to unusually low values, especially in the upper parts of the water column. We attribute the early increase of pulse amplitudes near the surface to bubbles from mixing of air and water at the hurricane-whipped surface; the increase near the bottom is attributed to sediments brought into suspension by strong bottom water motions, which does not often occur in this sheltered coastal region. The high concentration of suspended sediment subsequently penetrated well up into the water column. Clemente-Colon (1992) found sediment in the water visible in satellite imagery the next day. There is a 1.5 m "dead zone" between the ADCP transmitter and the bottom of the deepest measurement "bin." Our interpretation of the decrease of pulse amplitude at all measured levels is that after 0345 the concentration of suspended sediment became so large that the (unmeasured) attenuation within the dead zone was sufficient to substantially reduce the amplitude of pulses returned from levels higher in the water column. The vertical structure of pulse amplitudes after 0400 lends support to this conjecture. Another possibility, of course, is unknown and unknowable: damage to the instrumentation.

Some additional information about changes in the water column is provided by the ADCP in the form of information about the width of peak of the frequency spectrum of the acoustic pulses received. The pulse is emitted at a single frequency. Although the shortness of the pulse leads to some broadening of the spectrum, further broadening of the spectrum of pulses returned from a sampled level will be induced by anything that contributes to the heterogeneity of velocity of acoustic reflection within the sampled volume (RD Instruments, 1989). Moving fish, or small-scale turbulence, can broaden these spectra; larger scale motions such as those from major ocean waves do not. The temporal evolution of spectrum width (Fig. 7) shows a general increase, similar in most respects to that of the pulse amplitudes, as the hurricane approached.

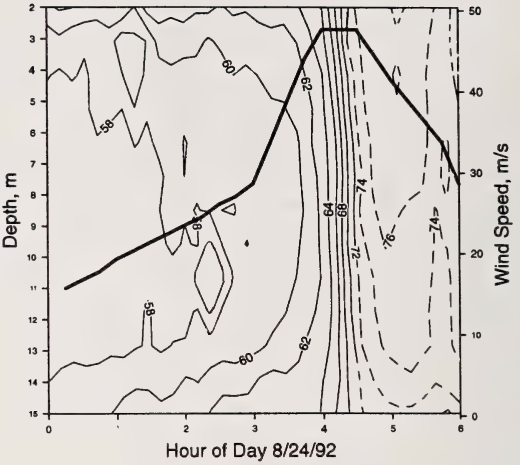


FIG. 7. Widths of peak in Hz of spectrum of ADCP acoustic pulses at different depths at DC during hurricane approach and passage. The instrument was overturned at about 0430 and later acoustic readings (dashed lines) are not valid. The thick line is wind speed.

We believe that the spectral broadening observed until about 0415 is best explained as due to increasing turbulence as the storm intensified and the waves grew larger. Like the pulse amplitudes, the pulse spectrum width increased first near the surface and the bottom where wind stress, breaking waves, and bottom shear are most efficacious in generating turbulence. The large spectral widths observed after about 0415 quite possibly are due to the very low pulse amplitudes received then, but no geophysical interpretation should be given data from this time in either Fig. 6 or 7.

DISCUSSION—Although the current measurement array design, and its early destruction by hurricane forces, precluded obtaining measurements adequate for description of the three-dimensional temporal evolution of storm-forced water movements, these rare measurements do provide some interesting information of these movements. First, the modest strength of the measured currents is somewhat surprising. Although the maximum average recorded current speed was larger than commonly observed in this area, average speeds nearly as large have been observed (Lee, 1975) during undisturbed weather when the Florida Current flowed close to shore.

However, there was ample evidence on the sea floor of much larger than normal apparently transient current forces. The destruction of the instrumentation designed to successfully endure normal extremes of conditions is but one example. The 225 kg low-profile ADCP and frame were toppled and displaced some 200 m. Sunken vessels intended as artificial fishing reefs seaward of sites DC and DN were about 50% destroyed (broken and displaced) (Mostkoff, 1993). In one instance a 65-m long steel barge was displaced more than 600 m westward. The only evident source of such forces is the oscillatory currents due to surface wind waves. Although artificial reef displacements were primarily westward, several instances of southwest, northwest, and even northward displacements were reported, reflecting the changing conditions during the storm and suggesting that currents averaged over several minutes in conjunction with the waves at times play a significant role.

Another somewhat surprising aspect of the average currents is their tendency toward vertical uniformity under extreme storm conditions. We speculate that this is a result of extreme wave-induced turbulence that effects rapid vertical transfer of momentum.

The wave currents and forces appear also to be particularly efficacious for eroding and resuspending bottom sediments, which then may be transported over considerable distances by the larger scale current patterns and redeposited in new areas. Divers observed notable changes in bottom contours near site DC after storm passage. Satellite imagery from the day following the landfall of Andrew (Clemente-Colon, 1992) shows heavy concentrations of suspended sediments in the coastal waters extended to about 26°N.

Some aspects of the currents remain enigmatic. As Andrew approached the coast, the coastal waters were subject to southward wind stress; southward currents are expected and were observed. Similarly, after hurricane landfall the coastal waters were subjected to northward wind stress, resulting in northward flow. The northward flow observed after 0500 has a significant eastward (offshore) component, which was not observed at site DN. The offshore flow at site DC likely is a response to the spatial gradient of wind speed, but may be influenced in part by the local north-northeast trend of the shoreline (Fig. 1). Most enigmatic are the Aanderaa meter observations between about 0345 and 0430. These data indicate onset of eastward current (at 16 m depth) while the wind still had a very strong westward component. While this might be interpreted as evidence for an upwind return flow in the near bottom layers, there is no support for this interpretation in the few coincident ADCP measurements available. It is easier to believe that the moored Aanderaa meters simply do not provide reliable measurements in such extreme conditions.

On the other hand, whenever the eastward flow did begin, it would have been running against the incoming wind-generated waves, converging wave energy, and may thereby have contributed to the rapid intensification of conditions. When waves over a shoaling bottom meet an opposing current, such as the ebb tide from an estuary, the waves become steeper and break farther offshore. When the current turned eastward, the large waves that had been breaking nearer shore appear to have begun to break at the ADCP site, causing the observed devastation and destruction of the instrumentation.

Acknowledgments—Several AOML personnel contributed to obtaining the Aanderaa current meter data. In particular, NOAA divers Jules Craynock and NOAA LT Lee Wiener installed and maintained the instruments. The existence of any ADCP current meter data is due entirely to their diligence in relocating and retrieving the instruments and parts of its mounting frame shortly after the storm. Robert Williams of NOAA/NOS supervised the installation of the ADCP and the initial processing of data from it, Barbara Tracy of the WES Wave Information Study furnished the wave model calculation results, Victor Wiggert of AOML contributed the storm surge model results, and Ben Mostkoff of the Dade County, Florida, Department of Environmental Resources Management provided information on effects of Andrew on the artificial reef structures. The manuscript was prepared by Gail Derr and graphics were done by Alejandra Lorenzo.

LITERATURE CITED

AANDERAA INSTRUMENTS. 1979. Operating Manual for RCM 4/5 Recording Current Meter Models 4/5. Aanderaa Instruments, Bergen.

CLEMENTE-COLON, P. 1992. Coastwatch and Andrew. Mariners Wea. Log. 36:26–27.

FONG, P. AND D. LIRMAN. 1994. Damage and recovery on a coral reef following Hurricane Andrew, 1994. Res. Explor. 10:246–248.

HALPER, F. B. AND W. W. SCHROEDER. 1990. The response of shelf waters to the passage of tropical cyclones: Observations from the Gulf of Mexico. Cont. Shelf Res. 10:777–793.

JELESNIANSKI, C. P., J. CHEN, AND W. A. SHAFFER. 1992. SLOSH: Sea, lake, and overland surges from hurricanes. NOAA Tech. Rept. NWS-98, Silver Springs, MD.

LEE, T. N. 1975. Florida spin-off eddies. Deep-Sea Res. 22:753–765.

——— AND D. A. MAYER. 1977. Low-frequency current variability and spin-off eddies along the shelf off southeast Florida. J. Mar. Res. 35:193–220.

LIRMAN, D. AND P. FONG. 1996. Sequential storms cause zone-specific damage on a reef in the northern Florida Reef tract: Evidence from Hurricane Andrew and the 1993 storm of the century. Florida Scient. 59 (1):50–64.

MAYFIELD, M. AND L. AVILA. 1993. Atlantic hurricanes. Weatherwise 46:18–25.

MOSTKOFF, B. 1993. Dade County Department of Environmental Management, Miami, FL, Pers. commun.

MURRAY, S. P. 1970. Bottom currents near the coast during Hurricane Camille. J. Geophys. Res. 75:4579–4582.

POWELL, M. D. AND S. H. HOUSTON. 1996. Hurricane Andrew's landfall in south Florida, Part II: Surface wind fields and potential real-time applications. Wea. Forecast. 11 (3):329–349.

RD INSTRUMENTS. 1989. Acoustic Doppler Current Profiler Principles of Operation: A Practical Primer. 36 pp.

SMITH, N. P. 1982. Response of Florida Atlantic shelf waters to Hurricane David. J. Geophys. Res. 87:2007–2016.

SNEDDEN, J. W., D. NUMMEDAL, AND A. F. AMOS. 1988. Storm and fair-weather combined flow on the central Texas continental shelf. J. Sed. Petrol. 58:580–595.

TILMAN, J. T., R. W. CURRY, R. JONES, A. SZMANT, J. C. ZIEMAN, M. FLORA, M. B. ROBBLEE, D. SMITH, R. W. SNOW, AND H. WANLESS. 1994. Hurricane Andrew's effects on marine resources. Bioscience 44:230–237.

TRACY, B. 1993. Corps of Engineers Waterways Experiment Station, Vicksburg, MS, Pers. commun.

WAKIMOTO, R. M. AND P. G. BLACK. 1994. Damage survey of Hurricane Andrew and the relationship to the eyewall. Bull. Am. Meteor. Soc. 75:189–200.

WIGGERT, V. 1993. NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, FL, Pers. commun.

Florida Scient. 60(4): 254–264. 1997
Accepted: May 27, 1997.

ARE LONE PAPER WASP FOUNDRESSES MAINLY THE RESULT OF SISTER MORTALITY?

Ronald M. Clouse

University of Florida, Department of Zoology, Gainesville, FL[1]

Abstract: *The origin of nest initiation by lone foundresses in the paper wasp* Mischocyttarus mexicanus *was investigated. Specifically, the hypothesis that these females are the lone survivors of former sister groups was tested. If this hypothesis were true, lone (haplometrotic) females would be indistinguishable from females that begin nests with sisters (pleometrotic females), especially those pleometrotic females that spend the most time on the nest and are the most likely to survive. Foundress sizes were compared from one population, and it was found that haplometrotic females were larger than high- and low-ranking pleometrotic females. Pleometrotic nests in another population were reduced to form "forced-lone" females; these females were less active than true haplometrotic females. Haplometrotic females also made more foraging trips than forced-lone females while spending an equal amount of time on their nests. These results do not support a sister-mortality hypothesis for haplometrosis but instead suggest that haplometrotis and pleometrosis are the result of two distinct nesting tactics.*

Reproductive female paper wasps (Vespidae: Polistinae) initiate nests either alone (haplometrosis) or with sisters (pleometrosis), often showing both tactics in the same species. This intraspecific variation makes paper wasps excellent candidates for studying in which situations and for which females social or solitary nesting behavior is more successful. However, it may be that either pleometrosis or haplometrosis is the best tactic in each species, and the other tactic is adopted only when the first is not possible. If the latter is true, paper wasps would become a less effective model for understanding the evolution of sociality. The purpose of this paper is to present a partial investigation into whether haplometrosis and pleometrosis are mainly the result of female choice or environmental limitations.

Explanations for variation in nesting behavior fall mainly into two categories: (1) those that explain the variation as a result of ecological constraints or stochastic events in the environment, and (2) those that attribute the variation to different tactics pursued by females regardless of the environment. Advocating the first paradigm, Reeve (1991) presented a model in which the main variable ("x"), which represented the expected payoff from attempting to establish a nest alone, was conceived as a measure of ecological constraints. A low value for "x" could result from highly limited nest sites, high mortality of lone females, and lateness in the nesting season, all of which were presented as functions of the environment. Ecological constraints could force females into either haplometrosis or pleometrosis: a reproductive female, indistinguishable from any other in the population, may be from a small nest with few or no sisters and thus ends up working alone simply because there is no one to join her (Klahn, 1979; Noonan, 1981); or she cannot find suitable nesting sites and works with sisters instead of not building a nest at all; or her sisters die after their nest has begun. Conversely, tactical hypotheses pose the possibility that haplometrotic and pleometrotic females are haplometrotic or pleometrotic mostly by their own choosing. That is, given the option of working alone or in a group, all else being equal, some females choose to work alone, and some choose to work with sisters. This could be the result of any factor that produces females of differing physical condition and a decision rule that correlates social behavior with condition (West-Eberhard, 1967). For example, reproductive females (gynes) could gain information about their condition by interacting with sisters on their natal nest before dispersing, and if they determine that they are the strongest and most fertile, they may decide to nest alone (Noonan, 1981; Grafen, 1984; Gadagkar et al., 1991). The causes of differences in reproductive condition and the different types of decision rules determining the choice of nest-initiation mode could have several different influences, from genetics to nutrition.

---

[1] Present address: Everglades National Park, Dan Beard Center, 40001 SR-9336, Homestead, FL 33034

Although we cannot measure the reproductive potential of future foundresses, we are able to test if haplometrotic females are just a subset of pleometrotic females, distinguished by having lost all of their sisters. If we compare any trait of haplometrotic and pleometrotic females, and if haplometrotic females are simply the result of pleometrotic females losing sisters, then this trait should not differ between the two groups. In addition, if we hypothesize that the most likely pleometrotic females to survive are those that remain on the nest most often (*i.e.,* the principal egg-layer), then we can test whether haplometrotic females are merely a subset of high-ranking pleometrotic females. The above tests were done in this study with the Southeastern paper wasp, *Mischocyttarus mexicanus.* I compared the sizes of pleometrotic and haplometrotic females, and I generated my own haplometrotic nests by removing females. We know already that haplometrotic Polistine females can be larger than pleometrotic females (Litte, 1977; Sullivan and Strassmann, 1984), that larger haplometrotic females can be more productive than smaller ones (Noonan, 1981), and that egg-laying pleometrotic females can be larger than foraging foundresses (Litte, 1977; Turillazzi and Pardi, 1977; Dropkin and Gamboa, 1981; Noonan, 1981; Strassmann, 1983; Sullivan and Strassmann, 1984).

Mischocyttarus mexicanus is common in Florida and Southern Georgia (Hermann et al., 1985). Females of *M. mexicanus* initiate nests year-round either alone or with close relatives, usually sisters (Litte, 1977). For tropical and subtropical paper wasps, such as *M. mexicanus,* foundress associations cannot be definitively distinguished from renesting mothers and daughters that have lost their nest to a storm or predator (Ito, 1993), unless one has been monitoring a population of marked females. Like other paper wasps, *M. mexicanus* foundress associations may contain over ten females (Litte, 1977), and foundresses usually form a linear hierarchy, with one female laying most of the eggs (Gamboa, 1978; Dew, 1983; Theraulaz et al., 1992). When the first daughters eclose, all foundresses maintain their previous roles, and daughters and foundresses forage and rear successive broods together. Reproductive females are produced at the end of the colony cycle.

METHODS—I worked first on Seahorse Key (hereafter SHK) in Levy Co., Florida, to measure wing lengths of nesting females. Located off the Gulf Coast of Florida, SHK is home to a large population of *M. mexicanus* that initiate nests in the leaves of cabbage palms (*Sabal palmetto*). Between 1 July and 11 August 1992, I found newly-initiated nests during the day in palms along the Southern shore and around the island's lighthouse. Nests were determined to be in the pre-eclosion phase if all cells were too small to have produced an adult.

I marked SHK females so that I could obtain behavioral data, and I measured forewing lengths as a indicator of body size. For each operation, I used a modified syringe that had a soft foam plunger and either a screen or clear plastic top. Females were enticed to sting the foam, pressed against the plastic top, and measured to the nearest 0.1 mm. Then they were transferred to the other syringe, pushed against the screen, and dabbed on the scutum with Testor's enamel paint through the screen.

To determine dominance rank, all pleometrotic nests at SHK were observed and the females dissected. Pleometrotic nests were censused during the afternoon at intervals of 30 minutes. As more nests were added, the interval between censuses increased, but never exceeded an hour. Attendance of each female was determined by simply calculating the percentage of censuses each female was present. All nests were censused at night to determine nest failures and female mortality. I also conducted 30- to 90-minute observations of each nest to note the nature of interactions between the residents of each nest (especially who bit whom). At the end of the SHK study, all females were frozen, and I determined ovary size and spermathecal content. I used five categories for ovary size, and spermathecae were categorized as full or empty. The highest-ranking female on each nest was determined by behavior and ovarian development: if a female was on the nest for the largest number of censuses, made the most bites, and had the largest ovaries, she was assigned the highest rank. For almost all cases, there were no ambiguities about which female was in this position, but for a few cases two females were both given the highest rank.

Between 10 May and 31 July, 1993, I worked at Archbold Biological Station (hereafter ABS), Highlands Co., Florida, and compared the behavior of haplometrotic and pleometrotic females. Nests were common there in saw palmetto (*Serenoa repens*) along roads and paths in mesic forest. Foundresses on 13 pleometrotic nests were marked and observed to determine trip duration. At ABS I marked females at night by touching a pine needle dipped in paint to their gasters; this method was faster than the SHK method.

I then reduced the number of females on 15 other pleometrotic nests at ABS to just one female. Seven of these nests required more then one attempt to remove all the females. These "forced-lone" nests were paired with 15 haplometrotic nests. Each pair was in the same general area and approximately the same size; however, the most important aspect of the pairing was that both nests were watched during the same time of day, since activity varies greatly with the time of day. On each of the haplometrotic nests, the foundress was touched with a pine needle and harassed to mimic the disturbance caused by removing females from the forced-lone nests. The only determinant of which females were removed was their ease in removal; at SHK I noticed that low-ranking females were more apt to attack small sticks and thus be removed, so I was probably more likely to remove lower-ranking females. (It should be noted that this observation is casual and contradicts nest-defense observations by Gamboa and co-workers (1992) for *Polistes fuscatus.*) Then each pair of nests was observed during the same one-hour period on consecutive days. Due to heavy storms, members of two pairs were observed two days apart, and members of another pair were observed three days apart.

During the observations at ABS, I recorded the occurrence of the following action patterns and events. They are based on over 30 hours of observations of 46 females at SHK. The SHK sample size upon which I based each definition is indicated in parentheses.

Arrive—(127) Wasp walks on to the nest from the substrate or lands on the nest from the air.

Depart—(126) Wasp leaves the nest for any period of time by walking or flying.

Wing raising—(210) First described by Hermann and Chao (1984), the wings are held at " . . . an angle of 57–107 degrees between wings, (avg. 84.6±13.7) and a mean angle of 38 degrees above the horizontal plane of the body." The antennae are held forward and are not moving, and the female stands on the meso- and metathoracic legs. The prothoracic legs are folded against the anterior thorax. This posture is one of the first stages in defense of the nest.

Chewing food—(27) Female stands on the meso- and metathoracic legs holding a prey mass between the prothroacic legs. She pinches the mass with the mandibles while rotating it with the prothoracic legs.

Pulp move—(28) Female alters the nest structure with her mandibles in one of two ways: (1) adding newly-foraged pulp or (2) moving paper from one part of the nest to another.

Nest lick—(4) Female opens her mandibles and rubs her mouth on the back of the nest (cell bases and pedicel) by rotating the head dorso-ventrally at a rate of two complete strokes per second. Wings are folded and resting on the dorsal surface on the abdomen, and all tarsi are in contact with the nest.

Gaster rub—(11) Female stands or walks around the back of the nest (cell bases) with her anterior pointing away from the pedicel. With terminal sternites in contact with the nest paper, the abdomen is moved to-and-fro along the anterior-posterior axis.

Head in cell—(2,242) Any part of the head (not counting the antennae) crosses the plane of any cell opening.

Fanning—(8) Female stands on meta- and mesothoracic legs while beating wings. The prothoracic legs are held folded against the anterior thorax, with the foretarsi not touching the nest paper. The head is held away from the nest surface, and the air is moved from the posterior to the anterior end of the body. The longitudinal axis of the body is at an angle of about 20 degrees to the nest surface, and the antennae are not moving. This action pattern was not recognized at first, since the wings are moving too fast to be seen, and the body vibrations are often too slight to be noticed.

Lay egg—(4) Female puts all tarsi on the edge of one cell while curling her abdomen into a cell. The abdomen stays in the cell for approximately 2 minutes. This action was preceded by 16 to 49 rapid "head in cell" movements at that cell and followed by at least four more "head in cell." It resulted in an egg being laid in the cell each of the four times it was observed.

When comparing the behavior of lone and forced-lone females at ABS, I also used the following behavioral calculation:

Activity—The cumulative frequency of "wing raising," "fanning," "pulp move," "gaster rub," and "nest lick," divided by the amount of time spent on the nest. I did not include "head in cell" in this calculation because it happened frequently enough to analyze separately. "Activity" was not calculated for one pair of nests on which one of the females was not present during the observation.

Measurement data from SHK were normal and analyzed using Fisher's PLSD. Rank data from SHK are analyzed using Wilcoxon Sign Ranks Test, with each "queen" (or mean of equally high-ranking females) paired with a mean of the subordinates on her nest. Behavioral data from ABS are in two general forms: data computed as a number of action patterns per minute spent on the nest, and data computed as a number of actions per hour the nest was watched. If there were enough pairs with non-zero differences, the data were compared using a Wilcoxon Sign Ranks Test. The test was one-tailed, since previous studies suggest that lone females are more active than pleometrotic females (and thus forced-lone females). Since this paper tests the general hypothesis that lone and forced lone females are the same, I corrected the p-values for each type of data using a Bonferoni interval. For the two comparisons of data computed as per minutes spent on the nest, individual p-values below 0.025 were considered significant, and for the six comparisons of data computed as per hour, individual p-values below 0.008 were considered significant. All data on foraging trip duration were averaged for each female observed. These averages were compared between lone, forced-lone, and pleometrotic females using a Kruskal-Wallis test ($p < 0.05$ significant), which was followed by a multiple comparison between lone and forced lone females ($p < 0.025$ significant).

RESULTS—At SHK haplometrotic females had longer forewings (10.49 ± 0.40 mm; $n = 32$) than low-ranking pleometrotic females (10.09 ± 0.50 mm; Fisher's PLSD; $n = 55$; $p < 0.01$). Haplometrotic females also had longer forewings than the highest-ranking pleometrotic females (10.16 ± 0.46 mm; $n = 22$; $p < 0.01$). In paired comparisons between the average size of high-ranking and low-ranking females from the same nest, no difference was found (Wilcoxon; $n = 17$ pairs; $p = 0.55$).

Behavioral studies at Archbold Biological Station revealed considerable differences between lone and forced-lone females (Table 1). Although there was no difference in the amount of time spent on the nest ($n = 12$; Wilcoxon; $p = 0.77$), lone females checked cells more often per unit time spent on the nest ($n = 14$; $p < 0.025$) and collectively performed other action patterns more often per minute on the nest ($n = 14$; $p < 0.025$). Cells on nests attended by lone females were checked more often per hour ($n = 14$; $p < 0.005$), and lone females made more foraging trips per hour ($n = 12$; $p < 0.0025$). Lone and forced-lone females were not significantly different in the number of gaster rubs or bouts of fanning and wing-raising performed per hour ($p > 0.008$). The average durations of trips by lone females (2.73 ± 1.15 minutes; $n = 12$), forced-lone females (6.42 ± 5.11 min.; $n = 9$), and multifoundresses still in groups (21.16 ± 21.51 min.; $n = 15$) were significantly different (Kruskal-Wallis; $p < 0.01$) Lone females tended to make quicker trips ($p < 0.20$), but the difference was not significant. Overall, lone females performed more action patterns per unit time spent on the nest than forced-lone females, especially for "head in cell" (Table 1, A and B; $p < 0.05$). And from the point of view of the offspring, lone and forced-lone females differed in the quality of care provided (Table 1, C–H; $p < 0.05$).

There was no significant difference in the delay between when females were harassed and observed for lone females (11.33 ± 7.74 days; range 1–

TABLE 1. Comparisons of lone and forced-lone females (means ± standard deviation). Sample sizes for paired nests ("n") represent the number of pairs that had non-zero differences. All analyses were done using the Wilcoxon Sign Ranks test (one-tailed). Family p-values for A and C and C–H are $p = 0.05$; p-values for individual comparisons, using Bonferoni intervals, are 0.025 for A & B, 0.008 for C–H. Significant differences are marked with an asterisk.

		Lone	Range	Forced-lone	Range	n	p
A	activity/minute on nest	0.66 ± 0.49	0.11–1.55	0.32 ± 0.23	0.09–1.24	14	<0.025*
B	head in cell/minute on nest	0.94 ± 0.92	0.08–3.27	0.47 ± 0.31	0.08–1.13	14	<0.025*
C	head in cell/hour	32.2 ± 21.93	5–80	15 ± 8.34	0–31	14	<0.005*
D	gaster rub/hour	3.87 ± 2.83	0–13	1.4 ± 2.41	0–9	12	<0.025
E	fanning/hour	8.47 ± 16.86	0–52	3 ± 7.64	0–25	9	<0.05
F	wing raising/hour	15.33 ± 9.06	3–32	7.07 ± 4.80	0–17	15	<0.01
G	minutes on nest/hour	44.97 ± 12.59	24.5–60	37.97 ± 18.34	0–60	12	0.77
H	number of trips/hour	7.83 ± 8.77	0–29.0	2.27 ± 2.72	0–9.5	12	<0.0025*

22) and had foundresses removed and observed for forced-lone females (7.80 ± 6.36 days; range 1–19).

Discussion—Litte (1977) also found that haplometrotic *M. mexicanus* females were larger than high-ranking females (and all pleometrotic females) (at ABS). However, although Litte found that high-ranking pleometrotic females were larger than foragers, this trend was not found at SHK. Other studies have found that high-ranking females were more active than low-ranking ones (Dew, 1983; Reeve and Gamboa, 1983). My finding low activity in forced-lone females is weakened by the difficulty in constructing an adequate control: "harassing" haplometrotic females may not adequately reproduce the removal of foundresses. However, in many paper wasps (including *M. mexicanus*), after the loss of the principal egg-layer, the next highest ranking female or oldest daughter quickly takes over the role of egg-layer, usually within hours (Hughes et al., 1987; Litte, 1977; West-Eberhard, 1967; Hermann et al., 1985; Hermann and Dirks, 1975; Litte, 1981; Gibo and Metcalf, 1978; Noonan, 1981; Hirose and Yamasaki, 1984; Willer and Hermann, 1989). In addition, where studied, it has been found that upon removal of foraging co-foundresses, the remaining "queen" immediately begins foraging (Litte 1981). In this study, females had over a week, on average, to adjust to foundress losses.

Most importantly, regardless of whether the behavioral experiment shows intrinsic behavioral differences between haplometrotic and pleometrotic *M. mexicanus,* haplometrotic females are clearly not just pleometrotic females that have lost sisters. It is difficult to imagine a natural scenario that could transform a population of foundresses having the physical qualities of SHK pleometrotic females into a population resembling SHK haplometrotic females. Moreover, at ABS lone females produced by my experiment did not mimic truly haplometrotic females behaviorally.

Large size and heightened activity could be important precursors of lone nesting success. All nests receive daily intrusions from conspecifics, and these intrusions can result in the loss of nests, larvae, and foundress lives (Gamboa, 1978; Gamboa et al., 1992; Brockmann, 1993; Clouse, 1995). Moreover, ants and birds hunt for wasp nests. Two possible ways to guard against these intrusions are (1) to work in groups so that there is always a guard on the nest (Gamboa et al., 1992), and (2) to make short foraging trips so as to leave the nest unguarded for only short periods. Lone and forced-lone females made quicker foraging trips than pleometrotic females in this study, and although the follow-up comparison between lone and forced-lone females did not show a significant difference, two facts suggest that lone females are more agile foragers. First, the trend was for lone females to make trips almost three times quicker than forced-lone females, but the sample sizes were small and the method of comparison conservative. Second, and more compelling, lone females spent the same amount of time on their nests as forced-lone females (with the trend toward lone females spending more time), but they left their nests over three times as often ($p < 0.0025$). Nesting alone thus requires being able to make quick foraging trips, as well as survive fights with conspecifics and other predators, lay viable eggs, and provide food and water for larvae. It is difficult to imagine how natural selection could favor small, inactive females nesting alone when joining sisters is a possibility.

Both the ecological constraints and tactical hypotheses have theoretical strengths and weaknesses. The strongest support for the ecological constraints hypotheses is that we know that some lone females are undoubtedly the result of a former group that lost members (pers. obs.) or are a female that has simply not found any sisters (Noonan, 1981). The fundamental weakness underlying the ecological hypotheses is that they allow the female wasp and her intrinsic attributes zero influence on nest-initiation mode. Reeve's measure of the severity of ecological constraints, "x", is no different mathematically from a measure of a female's individual ability to compensate for (or even exploit) those condition. Just as the environmental conditions encountered by each female may vary, so too would we expect their abilities to vary: thus it would seem very unlikely that we would find absolutely no difference between haplometrotic and pleometrotic females no matter what trait we measured. Females from small nests may be undernourished and smaller than average; females who remain after all their sisters have died on foraging trips may be the largest and most agile of the group. Moreover, there will always be important traits we cannot measure, and thus we can never accept the null hypothesis that there is no difference between lone and group-nesting females (For example, how do we measure their eyesight, the strength of their immune system, their ability to learn landmarks, etc.?).

The weakness of the ecological constraints hypotheses is the strength of the tactical ones. No matter how one measured the ability or potential to manage a new nest and rear reproductive offspring, we would expect the data to have some sort of distribution. If we add to this distribution two neurological pathways, one to recognize one's place in this distribution and another to alter one's nest-initiation behavior accordingly, then everything would be in place to produce variation in nest-initiation mode based on intrinsic properties of the females involved. The fundamental weakness of the tactical hypotheses is that there is presently no reliable way to measure reproductive potential: *e.g.,* do egg-laying females achieve their rank because of their large ovaries (Litte, 1977; Turillazzi and Pardi, 1977; Dropkin and Gamboa, 1981; Sullivan and Strassmann, 1984), or do they have large ovaries because of their rank? Are large females intrinsically better at laying eggs than small ones, or are they simply better at attaining the position of principal egg-layer and suppressing other females' ovaries?

The purpose of this article has not been to advocate the adoption of only a tactical explanation for variation in behavior. Rather, a more elaborate model is needed in which different individuals vary in how they engage with their environment. The environment is not random, although it may be difficult to predict; and the attributes of reproductive females are also not random, although they maybe resistant to change or difficult for the natal nest to control. Inasmuch as the environment is predictable and wasps can respond or evolve appropriately, we would expect a tight interlocking between the two. By analogy, if we dumped a box of toothpicks, some toothpicks would end up in piles and some scatter off by themselves, even though all had the same general shape and weight. On one hand, "ecological constraints" determine which toothpicks end up in piles or alone: uneveness of the floor, the order they fell out of the box, the angle at which the box was overturned, etc. However, if we measure the toothpicks with enough precision, we would find that they do differ in shape, weight and size. These differences could cause some toothpicks to settle to the bottom of the box, roll across the floor, or hold down other toothpicks more effectively than others. The hypothesis that piles or singles result only from constraints of the box or floor is thus transformed back into a hypothesis based on how the intrinsic qualities of the objects dropping interact with the substrate. The most useful hypothesis for explaining the position of any one toothpick (and thus wasp) is one that considers its individual traits in their appropriate ecological context.

ACKNOWLEDGMENTS—Drs. H. J. Brockmann, J. F. Anderson, and H. G. Hall invested a great deal of time helping this project at every level. Dr. G. J. Gamboa provided important suggestions on the final manuscript. Dr. F. Maturo allowed use of the University of Florida Marine Laboratory, and K. Litzenberger approved access to sites within the Lower Suwannee National Wildlife Refuge. Dr. P. Landolt instructed me in wasp dissection, and Dr. T. Singer helped identify wasps. The following volunteers helped census, watch and collect nests: E. Botsford, E. Clarke, P. Cushing, S. Moegenburg, M. Stowe, and J. Wood. Diane Riggs provided computer assistance. Archbold Biological Station, especially Dr. M. Deyrup, and the University of Florida provided funding, equipment, and access to expertise. This project was funded in part by a grant from Sigma Xi.

LITERATURE CITED

BROCKMANN, H. J. 1993. Parasitizing conspecifics: comparisons between Hymenoptera and birds. TREE 8:2–4.

CLOUSE, R. M. 1995. Nest usurpation and intercolonial cannibalism in *Mischocyttarus mexicanus* (Hymenoptera: Vespidae). J. Kansas Entomol. Soc. 68:67–73.

DEW, H. E. 1983. Division of labor and queen influence in laboratory colonies of *Polistes metricus* (Hymenoptera: Vespidae). Z. Tierpsychol. 61:127–140.

DROPKIN, J. A. AND G. J. GAMBOA. 1981. Physical comparisons of foundresses of the paper wasp, *Polistes metricus* (Hymenoptera: Vespidae). Can. Ent. 113:457–461.

GADAGKAR, R., S. BHAGVAN, K. CHANDRASHEKARA, AND C. VINUTHA. 1991. The role of larval nutrition in pre-imaginal biasing of caste in the primitively eusocial wasp *Ropalidia marginata* (Hymenoptera: Vespidae). Ecol. Entomol. 16:435–440.

GAMBOA, G. J. 1978. Intraspecific defense: Advantage of social cooperation among paper wasp foundresses. Science. 199:1463–1465.

———, G. J., T. L. WACKER, K. G. DUFFY, S. W. DOBSON, AND T. G. FISHWILD. 1992. Defense against intraspecific usurpation by paper wasp cofoundresses (*Polistes fuscatus,* Hymenoptera: Vespidae). Can. J. Zool. 70: 2369–2372.

GIBO, D. L. AND R. A. METCALF. 1978. Early survival of *Polistes apachus* (Hymenoptera: Vespidae) colonies in California: a field study of an introduced species. Can. Ent. 110: 1339–1343.

GRAFEN, A. 1984. Natural selection, kin selection, and group selection. Pp. 62–86. *In*: KREBS, J. R. AND N. B. DAVIES (eds.), Behavioral Ecology: an Evolutionary Approach. Blackwell Scientific Publications, Oxford.

HERMANN, H. R. AND J.-T. CHAO. 1984. Nesting biology and defensive behavior of *Mischocyttarus mexicanus cubicola* (Vespidae: Polistinae). Psyche 91:51–65.

———, H. R. AND T. F. DIRKS. 1975. Biology of *Polistes annularis* (Hymenoptera: Vespidae). I. Spring Behavior. Psyche 82: 97–108.

———, GONZALAS, J. M. AND B. S. HERMANN. 1985. *Mischocyttarus mexicanus cubicola* (Hymneoptera), distribution and nesting plants. Fla. Entomol. 68:609–614.

HIROSE, Y. AND M. YAMASAKI. 1984. Foundress associations in *Polistes jadwigae* Dalla Torre (Hymenoptera: Vespidae): Relatedness among co-foundresses and colony productivity. Kontyu 52:172–174.

HUGHES, C. R., M. O. BECK, AND J. E. STRASSMANN. 1987. Queen succession in the social wasp, *Polistes annularis.* Ethology 76:124–132.

ITO, Y. 1993. Behavior and social evolution of wasps. Oxford University Press, Tokyo.

KLAHN, J. E. 1979. Philopatric and nonphilopatric foundress associations in the social wasp *Polistes fuscatus.* Behav. Ecol. Sociobiol. 5:417–424.

LITTE, M. 1977. Behavioral ecology of the social wasp *Mischocyttarus mexicanus.* Behav. Ecol. Sociobiol. 2:229–246.

———. 1981. Social biology of the Polistine wasp *Mischocyttarus labiatus*: survival in a Colombian rain forest. Smithson. Contr. Zool. 327:1–27.

NOONAN, K. M. 1981. Individual strategies of inclusive-fitness-maximizing in *Polistes fuscatus* foundresses. Pp. 18–44. *In*: R. D. ALEXANDER AND D. W. TINKLE (eds.), Natural Selection and Social Behavior. Chiron Press, Inc., New York, NY.

REEVE, H. K. 1991. Polistes. Pp. 99–148. *In*: K. G. ROSS AND R. W. MATTHEWS (eds.), The Social Biology of Wasps. Cornell University Press, Ithaca.

———, H. K. ANDG. J. GAMBOA. 1983. Colony activity integration in primitively eusocial wasps: the role of the queen (*Polistes fuscatus,* Hymenoptera: Vespidae). Behav. Ecol. Sociobiol. 13: 63–74.

STRASSMANN, J. E. 1983. Nest fidelity and group size among foundress of *Polistes annularis* (Hymenoptera: Vespidae). J. Kansas Entomol. Soc. 56:621–634.

SULLIVAN, J. D. AND J. E. STRASSMANN. 1984. Physical variability among nest foundresses in the polygynous social wasp *Polistes annularis.* Behav. Ecol. Sociobiol. 15:249–256.

THERAULAZ, G., J. GERVET, B. THON, M. PRATTE, AND S. SEMENOFF-TIAN-CHANSKI. 1992. The dynamics of colony organization in the primitively eusocial wasp *Polistes dominulus* Christ. Ethology 91:177–202.

TURILLAZZI, S. AND L. PARDI. 1977. Body size and hierarchy in polygynic nests of *Polistes gallicus* (L.) (Hymenoptera: Vespidae). Monit. Zool. Ital. 11:101–112.

WEST-EBERHARD, M. J. 1967. Foundress associations in Polistine wasps: dominance hierarchies and the evolution of social behavior. Science 157:1584–1585.

WILLER, D. E. AND H. R. HERMANN. 1989. Multiple foundress associations and nest switching among females of *Polistes exclamans* (Hymenoptera: Vespidae). Sociobiology 16:197–216.

Florida Scient. 60(4): 265–274. 1997
Accepted: June 17, 1997.

REVIEW

Michael Collier, Robert H. Webb, and John C. Schmidt, *Dams and Rivers—Primer on the Downstream Effects of Dams.* U.S. Geological Survey Circular 1126, Tucson, Arizona, 1996. Pp. 94. Available from—U.S. Geological Survey, Branch of Information Services, Box 25286, Denver CO 80225.

This U.S. Geological Survey Circular (No. 1126) is one of only a few published efforts to synthesize the effects of dams on downstream ecosystems, in terms accessible to the general public. The authors note that virtually every river in the lower 48 states is regulated by dams, locks, or diversions; there are now more than 75,000 dams higher than 6 feet (about 1.8 meters) in the United States. Creating reservoirs equal to 3% of the nation's land surface, these dams store 60% of America's typical annual river flow. That dams produce enormous economic benefits is as clear to the authors that the time has come to reckon their ecological impacts.

This report examines an untamed river and six dammed rivers to illustrate natural and altered patterns of variation in hydrology, geology, water chemistry, and biology. Each account is written with informative historical, political, and economic background—"real" stories of how downstream rivers were impoverished. Empirical data are selected with care and presented in simple formats, and each account is accompanied with numerous color plates. A concluding chapter speaks to the roles of science in managing dammed rivers.

This report appears at an important time in Florida history. The Chattahoochee River in Georgia is a *Dams and Rivers* case study of impoundment and diversion with special meaning to Florida, for the Chattahoochee becomes the Apalachicola, a river and estuary system of state and national significance. Controversy surrounds de-commissioning of the Rodman Reservoir in the Oklawaha River, and research and engineering projects will unfold for decades to come as hydrological damages to the Florida Everglades are undone.

The authors rightfully echo the position of many Florida water managers, that society as a whole must decide what benefits and impacts must balance decisions over river regulation, but environmentalists will nonetheless detect an apologetic tone in the authors' claim that dams are here to stay. For a government agency, Collier et alia speak forcefully, "Scientists dealing with the downstream effects of dams—at levels ranging from basic research to applied engineering—must formulate questions whose answers can ultimately make a difference. To strive for anything less is to be just another bureaucrat."

I found *Dams and Rivers* historically significant, thought-provoking, and informative in the context of Florida's river science, especially for under-scoring how little sedimentology or channel hydrology have been employed as tools in state river management. Its main shortcoming is the lack of content addressing estuarine impacts of dams in coastal rivers, an oversight not uncommon even in contemporary texts on estuarine ecology. On balance, this primer and list of references are excellent resources for an introductory or multi-disciplinary course on river science and management.—Ernest D. Estevez, Mote Marine Laboratory, Sarasota, FL 34236.

REVIEW

Christopher Lever, *Naturalized Fishes of the World,* Academic Press, New York, 1996. Pp. xxiv + 408. Price: $49.95

SINCE the days of the Roman Empire, humans have sought to enhance their economic and recreational opportunities by transporting fish between countries. Due to technological limitations, relatively few translocations occurred until the latter half of the 19th century. Since then, however, translocations of fish species for food, sport, ornamentation, and ecological manipulation have proceeded at a rapid rate. Ecological impacts of these introductions can be severe, as in the case of the Nile Perch, which wiped out much of Lake Victoria's native fish fauna. However, the potential for economic gain has in most cases overridden any attempt to stem the flow of species between continents.

The severity of Florida's exotic species problem is very apparent from this book; of 56 exotic fish species naturalized in the United States, at least 30 of them are established in Florida. Florida's large aquaculture and aquarium fish trades provide a continuous flow of new potential colonizer species, and the state's fish species list will only expand in the future.

Naturalized Fishes of the World provides a comprehensive review of the translocation and naturalization of fishes around the planet during the last 2,000 years, and is the third volume in Lever's Naturalized Animals of the World series. The book consists of a series of species accounts, arranged in taxonomic order, for all species of fish known to be naturalized in countries outside of their native range. Each account includes a very brief description of the fish, information on the natural and naturalized distribution of the species, and, in some cases, information on the ecological impact of the naturalized populations. Widely-introduced species receive suitably thorough coverage. For example, the entry for Rainbow trout, (*Oncorhynchus mykiss*) fills 22 pages of text and describes naturalizations in 55 countries, while the Mosquitofish (*Gambusia affinis*) entry fills 10 pages and describes naturalizations in 65 countries. Single introductions of less familiar species such as the White Catfish, (*Ictalurus catus*) and the Three-lined Rasbora, (*Rasbora trilineata*), are also recorded. In total, Lever documents the naturalization of 205 fish species from 34 different families.

This work is very thoroughly researched. Literature on exotic fishes is widely scattered, and often appears in obscure foreign or regional publications. Lever has addressed this challenge admirably, citing over 1,000 publications. The acknowledgments note the cooperation of fish biologists around the world in providing the wealth of data herein. Most species accounts include information about the ecological impact of the introductions on the native ecosystems. Numerous examples of negative effects of fish introductions are described. The volume thus provides a rich body of evidence to refute those who downplay the negative impacts of naturalized species. It is attractively illustrated throughout with line drawings of many species, as well as global distribution maps for widely translocated species. A geographic index with listings by country and a taxonomic index with listings by Latin and common names are included, which greatly facilitates use of this book. American readers would benefit from a state-by-state geographic index, but this might be an unreasonable expectation.

The information presented in distribution maps does not always correspond with that in the text. For example, maps record the translocation of two cichlid species (*Oreochromis niloticus* and *O. urolepis hornorum*) to Florida, yet there is no mention of these events in the text. The author corrects numerous errors and inconsistencies found in previous publications, but makes a few of his own. Errors in place names are quite common; for example Fort Lauderdale is placed in Dade rather than Broward County on page 248. A reference to canals in "Dade County, South Miami, Florida" on page 303 should read "South Miami, Dade County, Florida." The canals described include the Little River Canal and Tamiami Canal, neither of which pass through South Miami. However these relatively minor geographical errors do not seriously detract from very thorough coverage of Florida translocations.

The Addendum consists of a selection of abstracts from a 1996 symposium on "Stocking and Introduction of Fish in Freshwater and Marine Ecosystems". The abstracts are of variable quality and relevance, and do not follow the species account format used throughout the book. Given the fact that the symposium proceedings will be published in their entirety in a separate volume, I must question the decision to include this section in Lever's volume.

Lever's book is a must for anyone studying exotic fishes, and it would be a valuable desk reference for anyone working in Florida's aquatic environments. It will prove particularly useful to those working in such diverse fields as aquaculture, fishery management, and aquatic ecosystem restoration. The price is very reasonable for this attractively and sturdily clothbound volume. Lever has successfully summarized the massive changes that human actions have wrought on the distribution of fish species around the world. Few regions have been so dramatically affected as the state of Florida. As we enter the new millennium, perhaps we will be inspired to adopt a more responsible approach to fish translocations in the future.—J. Jasper Lament, Department of Biology, University of Miami, Coral Gables, FL. 33124-0421. Jlament@fig.cox.miami.edu

OUTSTANDING STUDENT PAPER AWARDS

Florida Academy of Sciences
1997 Annual Meeting

ANTHROPOLOGICAL SCIENCES

Chris King, Department of Anthropology, Florida Atlantic University, "Metric Analysis of Sexual Dimorphism in the Humerus." Graduate Award.

Noah Teitelbaum, New College, "Bringing down the light: A Study of a New Age Millenarian Group." Undergraduate Award.

BIOLOGICAL SCIENCES

Stephanie Bringham, Barry University, "Sleep Cycles of Apnea-Eupnea in the Southern Elephant Seal *Mirounga leonina.*" Undergraduate Award.

Julianne Liesman, Department of Biological Sciences, Florida Institute of Technology, "Presence of the Ophiuroid Primary Circlet as an Indicator of Disturbance." Graduate Award.

ENGINEERING SCIENCES

Gredy Garrido, Florida Institute of Technology, "Continuous Quality Improvement in Engineering Education." Graduate Award.

ENVIRONMENTAL CHEMISTRY AND CHEMICAL SCIENCES

Rosa Negron, Department of Chemistry, University of South Florida, "Analytical Method Validation for the Separation of Testosterone and Related Steroids by Micellar Electrokinetic Capillary Chromatography Using Sensitized Terbium Fluorescence Detection." Undergraduate Award.

Wendy Foss, Department of Chemistry and Biochemistry, Florida Atlantic University, "Mechanism of Phosphonic Acid Adsorption Onto Aluminum Oxide." Graduate Co-Award.

Maria Gallardo, Institute for Environmental Studies, Department of Chemistry, University of South Florida, "Relative Concentrations of Allelophathic Materials in Cattail Plants." Graduate Co-Award.

FLORIDA COMMITTEE ON RARE AND ENDANGERED PLANTS AND ANIMALS

Laura Finn, Department of Biology, University of Central Florida, "Relocating Central Florida Bats: Can it be Done?" Graduate Award.

GEOLOGY/HYDROLOGY SCIENCES

Candace Trimble, Department of Geology, Florida Geological Survey and Florida State University, "Steinhatchee River Estuary, Taylor and Dixie Counties: A Comparison of Two Sediment Digestion Methods for Normalization of Trace Metal Concentraton Data." Graduate Award.

PHYSICS AND SPACE SCIENCES

Brent Goode, Department of Physics and Space Sciences, Florida Institute of Technology, "Determination of 3-dimensional Positions of Lightning VHF Pulses Using a Modified LDAR System." Undergraduate Award.

SOCIAL SCIENCES

Christina Cianci, Saint Leo College, "Expectations of the Elderly Regarding Counseling." Undergraduate Co-Award.

Donald McIlvaine, Saint Leo College, "A Survey of the Homeless Population in Pasco County." Undergraduate Co-Award.

SPECIAL AWARDS

AMERICAN ASSOCIATION OF THE ADVANCEMENT OF SCIENCE (AAAS) AWARD UNDERGRADUATE AWARDEES

Rosa Negron, University of South Florida, "Analytical Method Validation for the Separation of Testosterone and Related Steroids by Micellar Electrokinetic Capillary Chromatography using Sensitized Terbium Fluorescence Detection." Female Nominee.

Noah Teitelbaum, New College at the University of South Florida, "Bringing Down the Light: A Study of a New Age Millenarian Group." Male Nominee.

CENTRAL FLORIDA CHAPTER, THE EXPLORERS CLUB AWARD

Julianne Liesman, Department of Biological Sciences, Florida Institute of Technology, "Presence of the Ophiuroid Primary Circlet as an Indicator of Disturbance." For 1997.

Laura S. Finn, Department of Biological Sciences, University of Central Florida, "A Bat Survey on the Disney Wilderness Preserve and the Occurrence of a Rare Species: *Plecotus rafinesquii*." For 1996.

FLORIDA INSTITUTE OF TECHNOLOGY CHAPTER, SIGMA XI AWARD

Brent Goode, Department of Physics and Space Sciences, Florida Institute of Technology, "Determination of 3-Dimensional Positions of Lightning VHF Pulses Using a Modified LDAR System."

UNIVERSITY OF FLORIDA CHAPTER, SIGMA XI AWARD

Laura Finn, Department of Biology, University of Central Florida, "Relocating Central Florida Bats: Can It Be Done?"

—Daryl L. Shrader, Awards Committee Chair,
Mathematics Department, St. Petersburg Community College

ACKNOWLEDGMENT OF REVIEWERS

It is a distinct pleasure to acknowledge the cooperation, dedication, expertise, and service of the folowing persons, who generously contributed their time and experience in reviewing manuscripts for volume 60. Some kindly reviewed more than one manuscript.

D. Gray Bass, Jr.
Robert S. Braman
Richard Cailteux
Bruce C. Cowell
James Cox
Clinton J. Dawes
C. Kenneth Dodd
Cherie D Geiger
Boris Galperin
Dilna Victor Hale
Richard Hammerschlag
Ann F. Johnson
Steve Johnson
Joseph J. Krzanowski
James N. Layne
Barbara B. Martin
Ken Langeland
Eric Menges
Larry Newton
George M. Padilla
Patrick Pitts
Steven G. Richardson
Clay Scherer
Ned Smith
William H. Taft
Walter Kingsley Taylor
John Winchester
Linda Wolfe
Charles A. Woods
Richard P. Wunderlin

FLORIDA SCIENTIST

QUARTERLY JOURNAL
OF THE
FLORIDA ACADEMY OF SCIENCES

VOLUME 60
Dean F. Martin
Editor
Barbara B. Martin
Co-Editor

Published by the

Florida Academy of Sciences, Inc.
Indialantic, Florida
1997

The Florida Scientist continues the series formerly issued as
the Quarterly Journal of the Florida Academy of Sciences.
The Annual Program Issue is published independently of the journal
and is issued as a separately paged Supplement.

Copyright © by the FLORIDA ACADEMY OF SCIENCES, Inc. 1997

CONTENTS OF *FLORIDA SCIENTIST* VOLUME 60

Number One

The Herpetofauna of Buck Island Ranch: An Altered Wetland in South-Central Florida .... Walter E. Meshaka, Jr. 1
Water Quality Measures on Florida Dairies: Issues of Regulation and Farm Size .... P. F. Monaghan, M. E. Swisher, and H. H. Van Horn 8
Responses of Two Closely Related Rail Species, *Rallus Longirostris* and *Rallus Elegans,* to Conspecific and Heterospecific Calls .... Ali M. Rabatsky 16
Studies on Florida Chrysophyceae (Paraphysomonadaceae) and Synurophyceae (Mallomonadaceae). V. The Flora of North-Central Florida .... Daniel E. Wujek and Peter A. Siver 21
Acknowledgment of Reviewers 27
Water-Soluble Mutagen Production During the Bioremediation of Oil-Contaminated Soil .... William C. Blodgett, Jr. 28
The First Record of *Artibeus jamaicensis* Leach (1821) from the United States .... Philip A. Frank 37
Respiratory Stategies of a Non-Native Florida Cichlid, *Cichlasoma octofasciatum* .... Claire O. Obordo and Lauren J. Chapman 40
An Introduction to the Tides of Florida Bay .... Ned P. Smith 53

Number Two

Observations of Pineywoods Dropseed (*Sporobolus junceus*) Phenological Development Following Fire in a Sandhill Community .... Susan Littell Canfield and George W. Tanner 69
Stability of Silica Gel for Supported Chelators .... Charles D. Norris, Robert F. Benson, and Dean F. Martin 73
Maucha Diagrams and Chemical Analyses to Diagnose Changes in Lake Chemistry .... Andrew L. Hassell, Patricia M. Dooris, and Dean F. Martin 75
Heavy Metal Contamination in Sediment From Crane Creek, Florida .... Thomas K. Gregory and Matthew A. Charette 81

Observations of Insects Associated With an Infestation of Sand Pine (*Pinus clausa*) by the Aphid *Cinara pinivora* ....
R. M. Clouse, B. Ferster, and M. A. Deyrup 89
A Preliminary Analysis of Neogene Depositional Environments in Broward County, Florida ....
Charles W. Finkl, Jnr. and Luciana S. Esteves 94
The Impact of Lake Restoration on the Zooplankton Community in Banana Lake, Polk County, Florida ....
John A. Osborne and Mary R. Egan 104
Predation on an Evening Bat (*Nycticeius* sp.) by Squirrel Monkeys (*Saimiri sciureus*) in South Florida ....
Linda L. Taylor and Shawn M. Lehman 112
Effects of Fire on an Endangered Florida Plant, *Deeringothamnus rugelii* ....
Joseph H. Helkowski and Eliane M. Norman 118
Production of Wheat and Triticale on Reclaimed Phosphatic Clay Settling Areas in Central Florida ....
C. S. Gardner, G. M. Prine, R. D. Barnett, and E. C. French 124

Number Three

Selected Life History Attributes of the Exotic Jaguar Guapote (*Cichlasoma managuense*) in Florida ....
Kelly Gestring and Paul Shafland 137
Pollination Ecology of the Rare Scrub Mint *Dicerandra frutescens* (Lamiaceae) ....
Mark Deyrup and Eric S. Menges 143
The Effects of Azadirachtin on Larval Stages of the Oak Toad, *Bufo quercicus* (Holbrook) ....
Fred Punzo 158
Literature Search for Air Quality Studies Conducted in Jacksonville, Florida, 1945–1995 ....
R. Del Delumyea, Tonya McKay, and Jennifer Horowitz 166
Trends in Air Quality Research in Northeast Florida, 1945–1995 and Comparison of Air Quality in Jacksonville, FL with Nine Other Cities in the United States, 1972–1992 ....
R. Del Delumyea, Tonya McKay, and Jennifer Horowitz 175
Utility of a Camera System for Investigating Gopher Tortoise Burrows ....
Donald M. Kent, Michael A. Langston, David W. Hanf, and Peter M. Wallace 193
Observations of Vertebrates Associated with Gopher Tortoise Burrows in Orange County, Florida ....
Donald M. Kent, Michael A. Langston, and David W. Hanf 197

Identification of Allelopathic Chemicals in a Pond of Cattails ....
Joaquìn Albalat Domènech, Eileen Pérez, Maria T. Gallardo, and Dean F. Martin 202
Florida Academy of Sciences Medalists 204

Number Four

First Documented Nesting by the Green Turtle (*Chelonia mydas*) Along the Southwest Coast of Florida ....
Allen M. Foley 205
Comparative Analysis of Growth, Nutrition, Carbon Isotope Ratios, and Hurricane-related Mortality of Slash Pines in South Florida ....
Steven F. Oberbauer, Piyal S. Kariyawasam, and James N. Burch 210
Volumetric Exchanges Between a Managed Marsh and a Coastal Estuary ....
Ashok Pandit, John H. White, Antonis A. Kakoullis, Satish B. Akula, and James R. David 223
High Breeding Density of Common Moorhens at a Zoological Park ..
Brett K. Bannor 236
Behavior of Sea Turtles at an Urban Beach III. Costs and Benefits of Nest Caging as a Management Strategy ....
Stephanie L. Adamany, Michael Salmon, and Blair E. Witherington 239
Coastal Currents Induced by Hurricane Andrew ....
William McLeish, Donald V. Hansen, and John R. Proni 254
Are Lone Paper Wasp Foundresses Mainly the Result of Sister Mortality? ....
Ronald M. Clouse 265
Book Review ....
Ernest D. Estevez 275
Book Review ....
J. Jasper Lament 277
Awards ....
Daryl L. Shrader 279
Acknowledgment of Reviewers 281
Table of Contents, Volume 60 285

INSTRUCTION TO AUTHORS

Individuals who wish to publish in the *Florida Scientist* must be active members in the Florida Academy of Sciences.

Submit a typewritten original and two copies of the text, illustrations, and tables to the editors. All typewritten material–including the abstract, literature citations, footnotes, tables, and figure legends–shall be double-spaced. Use one side of 8½ × 11 inch (21½ cm × 28 cm) good quality bond paper for the original; the copy may be xeroxed. Margins should be at least 3 cm all around. Number the pages through the Literature Cited section. Avoid footnotes and do not use mimeo, slick, erasable, or ruled paper. Use metric units for all measurements. *Papers in excess of 10 pages by an author in a single volume will result in page charges ($57 per page) for the excess pages.*

Address follows the author's name.

Abstract–all manuscripts shall have a short, concise, single-paragraphed abstract. The abstract follows immediately the author's address.

Acknowledgments are given in the body of the text preceding immediately the Literature Cited section.

Literature Cited section follows the text. Double-space every line and follow the format in the current issue.

Manuscripts of 5 or less, double-spaced typewritten pages should conform to the short article protocol. See recent issue for proper format of both long and short articles.

Tables shall be typed on separate sheets of paper, double-spaced throughout. Each table shall contain a short heading. Do not use vertical rulings. Maximum character width, including spaces, of tables is 98.0. This includes a minimum space of 5 characters between columns.

Illustrations–All drawings shall be done in good quality India ink, on good board or drafting paper. Letter by using a lettering guide or equivalent. Typewritten letters on illustrations are unacceptable. Drawings and photographs should be large enough to allow ⅓ to ½ reduction in size. Photographs shall be glossy prints of good contrast. Whenever possible, mount photographs in lots size.

The author's name and figure number should be penciled lightly on the back of each figure. Figure legends must be listed on a separate page and not on the drawing or photograph. The legend must be double spaced. Illustrations are charged to authors at $16.00 for halftones and $11.00 for line art.

We ask authors to prepare accepted manuscripts in personal computer formats. **Please do not submit a manuscript on disk.** Once reviewers have recommended a manuscript be accepted, you will be given directions for submitting the **final manuscript on disk.**

Proof must be returned promptly. Notification of address change and proofreading are the author's responsibility. Alterations after the type has been set will be charged to the author.

Reprints may be ordered through the Business Manager from the printer on forms provided at the time that proofs are sent to authors for checking.

FLORIDA ACADEMY OF SCIENCES

Institutional Members for 1997

Brevard Community College, Palm Bay
The British Library, Boston Spa, Weatherby, UK
The British Library, RAS Washington DC Professional Campus
Cleveland Public Library, Cleveland, OH
Edison Community College
Florida International University
Harbor Branch Oceanographic Institution, Inc.
Long Island University
Orlando Science Center
St. Petersburg (FL) Junior College
St. Thomas University
St. Thomas University Library
Saint Petersburg Public Library
Science Library, University of Chicago
University of Miami
University of North Carolina at Wilmington

Membership applications, subscriptions, renewals, and changes of address, should be addressed to the Executive Secretary, Florida Academy of Sciences, Orlando Science Center, 777 Princeton St., Orlando, FL 32803

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 University Blvd., Melbourne, FL 32901-6975 [(407) 768-8000, ext. 8196; e-mail rturner@fit.edu]

PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Prices quoted include domestic postage. Some issues may not be available. All are $20 per volume or $5 per issue, except for symposium issues.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES (1936–1944)
Volumes 1–7
QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCE (1945–1972)
Volumes 8–35
FLORIDA SCIENTIST (1973–)
Florida's Estuaries—Management or Mismanagement?—Academy Symposium
FLORIDA SCIENTIST 37(4)–$5.00
Land Spreading of Secondary Effluent—Academy Symposium
FLORIDA SCIENTIST 38(4)—$5.00
Solar Energy—Academy Symposium
FLORIDA SCIENTIST 39(3)—$5.00 (includes do-it-yourself instructions)
Anthropology—Academy Symposium
FLORIDA SCIENTIST 43(3)—$7.50
Shark Biology—Academy Symposium
FLORIDA SCIENTIST 45(1)—$8.00
Future of the Indian River System—Academy Symposium
FLORIDA SCIENTIST 46(3/4)—$15.00
Second Indian River Research Symposium—Academy Symposium
FLORIDA SCIENTIST 53(3)—$15.00

Please send payment with order. If required, an invoice will be sent on purchases over $20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.

ISSN: 0098-4590

Florida Scientist

FLORIDA ACADEMY of SCIENCES 1936

Volume 61 Winter, 1998 Number 1

CONTENTS

Growth Response of Dioecious Hydrilla to Phosphorus and Bicarbonate Utilization .... Kerry K. Steward 1

Occurrence of the Manta Ray, *Manta birostris,* in the Indian River Lagoon, Florida .... Douglas H. Adams and Elena Amesbury 7

Management of the Florida Red Tide—Revisited .... Dean F. Martin and William H. Taft 10

Enhanced Solubility of Sodium Fluorosilicate Scale by Magnetic Treatment .... Chuhua Wang, Robert F. Benson, and Dean F. Martin 17

Analysis of Selenium: An Annotated Bibliography .... Eileen Pérez, Gregory S. Corbett, Christopher J. Coston, Maria T. Gallardo, James D. Hayes, and Dongxin Wang 26

Desmognathus auriculatus at Devil's Millhopper State Geological Site, Alachua County, Florida .... C. Kenneth Dodd, Jr. 38

Effects of Humic Acid on The Solubility Product Constants of Some Environmentally Significant Calcium Compounds .... Warren C. Fiskus and Thomas J. Manning 46

An Annotated Bibliography of Allelopathic Properties of Cattails, *Typha spp.* .... Maria T. Gallardo, Barbara B. Martin, and Dean F. Martin 52

Review .... Frederick B. Essig 59

Books Received 60

SMITHSONIAN
MAR 05 1998
LIBRARIES

FLORIDA SCIENTIST

Quarterly Journal of the Florida Academy of Sciences
Copyright© by the Florida Academy of Sciences, Inc. 1998
Editor: Dr. Dean F. Martin Co-Editor: Mrs. Barbara B. Martin
Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, Florida 33620-5250
Phone: (813) 631-4121; e-mail: Martin@chuma.cas.usf.edu

Business Manager: Dr. Richard L. Turner
Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975
Phone: (407) 768-8000, ext. 8196; e-mail: rturner@fit.edu

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at $40.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

Officers for 1997–1998
FLORIDA ACADEMY OF SCIENCES
Founded 1936

President: Mr. Al Hall
City of Tallahassee
4335 Sherborne Road
Tallahassee, FL 32303

President-Elect: TBA

Secretary: Dr. Richard March
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416

Treasurer: Mrs. Georgina Wharton

Executive Secretary: Ms. Geralyn Heartz
Orlando Science Center
777 East Princeton St.
Orlando, FL 32803
407:896-7151, ext 2079; e-mail:
gheartz@osc.org

Program Chairs: Dr. George M. Dooris
and Dr. Patricia M. Dooris
Department of Science and Mathematics
St. Leo College
St. Leo, FL 33574

Published by The Florida Academy of Sciences, Inc.
Printing by Allen Press, Lawrence, Kansas

Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

DEAN F. MARTIN, *Editor* BARBARA B. MARTIN, *Co-Editor*

Volume 61 Winter, 1998 Number 1

Biological Sciences

GROWTH RESPONSE OF DIOECIOUS HYDRILLA TO PHOSPHORUS AND BICARBONATE UTILIZATION

KERRY K. STEWARD

Aquatic Plant Management Laboratory, Agricultural Research Service,
U.S. Department of Agriculture, 3205 College Avenue,
Ft. Lauderdale, FL 33314

ABSTRACT: *The phosphorus (P) requirement of the dioecious submersed aquatic plant hydrilla [*Hydrilla verticillata *(L.f.) Royle], was studied by culturing plants from vegetative propagules in nutrient solutions simulating natural levels and containing bicarbonate and 0, 2, or 4 μM P concentrations. Plants were harvested after 14, 21, 28, 35 and 50 days growth in order to follow the effects of the treatments on the time course of growth and P and bicarbonate utilization. The dry weight, total P accumulation, and bicarbonate utilization of plants increased with greater concentrations of P in solutions and longer growth time. Bicarbonate utilization was significantly related to increase in plant dry weight and P accumulation. The accumulation of P in tissue was proportional to concentration of P in solution. The total P content of plants grown without added P remained constant through 7 weeks of growth. The P reserves in the propagules of these plants were sufficient to produce a dry matter yield of 1127 mg after 50 days. The addition of 1.3 mg P in the 2 μM P treatments produced a 57% increase in yield over the same time period, or nearly 500 mg tissue per mg of added P. Approximately 72% of the P supplied in solution was absorbed by the plants in both the 2 and 4 μM P treatments. The results of this study suggest that hydrilla has a low requirement for P and is able to utilize bicarbonate as a carbon source for photosynthesis.*

HYDRILLA [*Hydrilla verticillata*(L.f.)Royle], a submersed vascular hydrophyte, once established in the wild, most often exhibits weedy growth and consequently becomes very troublesome (Pieterse, 1981; Swarbrick et al., 1981). The broad range of this plant (Cook and Lüönd, 1982; Cook, 1985; Pieterse, 1981; Swarbrick et al., 1981) indicates a tolerance for diverse habitats, especially those of diverse water quality.

It is a given that aquatic plants evolved and developed under environ-

TABLE 1. Inorganic nutrient solution for hydrilla culture.

Nutrient salt concentration		Nutrient element concentration (ppmw)
2.0	mM $CaC1_2-2H_2O$	Ca:80, C1:141
0.1	mM KNO_3	K:4, N:1.4
4.0	mM $NaHCO_3$	Na:92, HCO_3:244
1.0	mM $MgSO_4-7H_2O$	Mg:24, SO_4:96
4.0	μM KH_2PO_4	K:0.16, P:0.12
2.0	μM KH_2PO_4	K:0.08 p:0.06
4.5	μM H_3BO_3	B:0.05
0.9	μM $MnCl_2-4H_2O$	Mn:0.06
0.03	μM $CuCl_2-2H_2O$	Cu:0.002
0.1	μM MoO_3	Mo:0.0009
0.075	μM ZnAcetate	Zn:0.005
18.0	μM Fe chelate	Fe:1

mental conditions that were more pristine than the present conditions. The activities of the *populus* discharging materials into the environment have altered natural supplies and balances. The natural supplies of nutrients, required for growth of these plants, were most often restricted and consequently their growths were also restricted. Phosphorus is often considered the least naturally abundant macro nutrient for plant growth, since its supply is most limited (Epstein, 1972; Hutchinson, 1975). It has been speculated that increased environmental supplies of phosphorus through land runoff and effluent discharges into waterbodies is responsible for nuisance growths of hydrilla and other aquatic plants. These studies were an attempt to determine the phosphorus requirements for growth of hydrilla in controlled environments. In earlier studies, this investigator obtained evidence of utilization of bicarbonate by hydrilla as a carbon source (Steward and Elliston, 1973; Steward, 1991). A secondary objective was to confirm the results of these observations.

METHODS AND MATERIALS—*Plant materials*—Subterranean turions (tubers) of dioecious Florida hydrilla were collected from the hydrosoil of outdoor aquaria in which hydrilla had been previously cultured. These propagules were surface sterilized for 15 secs with 0.1% mercuric chloride and held in the dark in −P nutrient solution until germinated. After 12 days, 5 germinated tubers, ranging from 35–65 mm long, were randomly selected and placed in wide mouth jars. Each jar contained 3.5 L of defined nutrient solution containing 0, 2 or 4 μM concentrations of phosphorus (Table 1). Solutions were changed weekly and measurements were taken at weekly intervals of total dry weight of plants, tissue concentration of phosphorus and bicarbonate utilization. Utilization was determined by measurement of bicarbonate residues prior to solution changes. Bicarbonate and pH measurements were taken of fresh and week-old complete solutions, without plants, to establish base-line values. Values of bicarbonate residues were subtracted from base-line values to calculate bicarbonate utilization. Values of dry weight and tissue concentrations of P were used to estimate amounts of total P absorbed by the plants. Experiments were conducted in growth chambers. Temperature was maintained at 28 ± 2° C. Plants in chambers were exposed to 12-hr photoperiods of 315 $\mu E.m^{-2}.s^{-1}$ light supplied by VHO-Cool white and VHO-Daylight fluorescent lamps (1:1) and six 40-watt incandescent

TABLE 2. Growth response of hydrilla to micro-molar phosphorus treatment.

Growth in days	OP	2P	4P
		Total dry weight (mg)	
14	436 f[1]	434 f	436 f
21	662 e	649 e	600 ef
28	758 e	951 d	965 d
35	1006 d	1274 c	1262 c
50	1127 cd	1989 b	2266 a
		Total tissue phosphorus (μg)	
14	715 hi	852 gh	1024 def
21	1019 fg	1118 def	1286 d
28	762 hi	1206 def	1850 b
35	793 hi	1221 de	1899 b
50	622 i	1562 c	2541 a
		Bicarbonate utilization (mg/L)	
14	98 ef	84 f	98 ef
21	120 de	114 de	127 de
28	112 def	163 c	177 c
35	127 de	185 c	190 c
50	134 d	491 b	664 a

[1] Values followed by the same letter within parameters are not different using Waller-Duncan test, K ratio = 100.

bulbs. Harvested plant materials were rinsed with distilled water and oven dried to constant mass at 70° C.

Analytical procedures—Plant tissues were analyzed for total phosphorus following wet-ashing of the tissue in a nitric-perchloric acid mixture. Phosphorus content was determined colorimetrically as orthophosphate-P by the ascorbic acid method (APHA, 1985). Bicarbonate concentrations were determined as bicarbonate alkalinity through acid titration (APHA, 1985). Treatments were arranged as randomized complete blocks with five replicates as blocks. Data analysis was accomplished using SAS ANOVA and GLM procedures for personal computers (SAS Institute Inc., Box 8000, Cary, NC 27511).

RESULTS AND DISCUSSION—Mean and standard deviation of bicarbonate concentrations of fresh solutions were 240.8 ± 8.7 mg/l. The pH of solutions were 8.1 for minus P (OP) and 8.2 for 4 μM P (4P) solutions. One week old control solutions for base line contained 219.9 ± 11.7 mg/l bicarbonate. The pH of spent solutions varied with time, for example, OP solutions ranged from pH 7.9 to pH 8.3 and 4P solutions ranged from pH 8.0 to 8.9. Dry weights of plants grown in 2 μM P (2P) or 4P solutions were greater after 28 days than plants grown in minus P (0P) solutions for the same length of time (Table 2). The dry weight of plants grown in 4P treatments was greater than those in 2P treatments from 28 days onward, indicating that P supply may have been inadequate at 2P levels. Except for the anomaly at 21 days growth, there was no change, over time, in the total amount of P in plants grown in 0P solutions (Table 2). Total P level in plants did not appear to exceed initial levels until after 21 days growth in 2P treatments. Uptake of P seems to have occurred before 14 days in the 4P treatments and continued through to the final harvest. Although total P was greater in 4P treatments than in 2P treatments beyond 21 days growth, a dry weight growth response was not obvious until 50 days (Table 2). Total accumulation of P was related directly to P concentration of solutions. After 50 days growth, plants grown in 4P solutions contained 2541 micrograms of P which represented 74% of the total amounts applied after correcting for initial amounts in tissue. Plants grown in the 2P solutions contained 1562 micrograms of P which was 72% of the total amount applied. The initial amounts of P in the tubers, which were used to propagate the plants in this study, were sufficient to support growth of plants in the 0P solutions for 50 days. There was a close relationship between tissue content of P and plant dry weight ($r = 0.7110$ at $p = 0.01$). A small 0.4 mg increase in P uptake ($1206 - 762 = 444$ μg P, Table 2) produced an 0.2 gm increase in dry weight after 21 days in the 2P treatment ($951 - 758 = 193$ mg dry wt, Table 2). This is a 500:1 increase on a dry weight basis and approximately a 5000:1 increase on a fresh weight (FW) basis and is indicative of a low phosphorus requirement. This growth response is equivalent to one metric ton of fresh hydrilla produced by 200 grams of P (2.2 tons FW per 7 oz P).

Bicarbonate utilization was influenced by growth time and P supplies (Table 2). The least amount of bicarbonate was utilized by plants grown in the 0P solutions and the greatest utilization was by plants in the 4P solutions. Bicarbonate utilization was strongly related to increase in dry weight ($r = 0.9032$ @ $P = 0.01$) and was also closely related to P accumulation ($r = 0.7462$ @ $P = 0.01$).

Submersed aquatic plants, including hydrilla, depend on dissolved inorganic carbon (DIC) for photosynthesis (PS). Carbon dioxide is the preferred form for PS but its availability decreases rapidly with increasing pH due to kinetics of chemical equilibria in water (Stumm and Morgan, 1970). Approximately 96% of DIC is present as free CO_2 at pH 5, 21% at pH 7 and 0.3% at pH 9. Availability of bicarbonate (HCO_3^-) has an inverse relationship to free CO_2, that is, 97% of DIC is present as HCO_3^- at pH 9, 79% at pH 7 and 3.8% at pH 5. The photosynthetic rates of submersed plants which appear to only utilize CO_2 are strongly pH dependent. Rates of PS of these plants closely follow profiles of free CO_2 concentration in water and fall to zero at approximately pH 9 (Bain and Proctor, 1980; Sand-Jensen, 1987). The photosynthetic rates of aquatic plants which have been found to utilize HCO_3^- for PS continue beyond pH 9 but at reduced rates of approximately 10% of maximum under these alkaline conditions (Allen and Spence, 1981). The pH of the nutrient treatment solutions in the present study ranged from pH 7.9 to 8.9, a range where the availability of dissolved CO_2 was rapidly decreasing and HCO_3^- was nearly at maximum and increasing. Under these conditions the utilization of bicarbonate seems assured.

Angelstein (1910, as reported by Prins and Elzenga, 1989) provided the first evidence that utilization of bicarbonate for PS occurred in submersed aquatic macrophytes. General acceptance was late in coming however and not until additional evidence was provided through the work of others, extending from 1921 through 1960 (Prins and Elzenga, 1989).

Prins and Elzenga (1989) state that transport of bicarbonate across a cell membrane is difficult to distinguish from the transport of molecular carbon dioxide or the undissociated carbonic acid. There is little agreement about which form of DIC actually crosses the membrane, even when there is ample evidence that bicarbonate is utilized for PS. These authors qualify the term "bicarbonate utilization" to imply that bicarbonate acts as a DIC source for PS and that active transport mechanisms are involved but without decision as to what form crosses the membrane.

The significant growth response of hydrilla to small increases in phosphorus supply is evidence that increases in natural supplies of this nutrient element may indeed be partially responsible for nuisance growths of this plant. The relationships between bicarbonate utilization, phosphorus uptake and dry weight increase is strong evidence of the plants' ability to use this solute source of carbon for photosynthesis. This also explains in part the successful colonization of Florida's predominantly alkaline waters by hydrilla.

The results of this present study confirm previous evidence that hydrilla utilizes bicarbonate as a DIC source for PS (Bowes and Salvucci, 1989; Holaday et al., 1983; Prins et al., 1982; Salvucci and Bowes, 1983; Steward and Elliston, 1973).

ACKNOWLEDGMENTS—The author greatly appreciates the helpful comments of Drs. D. L. Sutton, Univ. of Florida, Fort Lauderdale; S. H. Kay, NCSU, Raleigh, N.C. and T. K. Van, USDA, ARS Fort Lauderdale, FL.

LITERATURE CITED

ALLEN, E. D. AND D. H. N. SPENCE. 1981. The differential ability of aquatic plants to utilize the inorganic carbon supply in fresh waters. New Phytol. 87:269–283.

APHA. 1985. Standard methods for the examination of water and wastewater. 16th Ed., Amer.Pub. Health Assn., Washington, DC.

BAIN, J. T. AND M. C. F. PROCTOR. 1980. The requirement of aquatic bryophytes for free CO_2 as an inorganic carbon source: Some experimental evidence. New Phytol. 86:393–400.

BOWES, G. AND M. E. SALVUCCI. 1989. Plasticity in the photosynthetic carbon metabolism of submersed aquatic macrophytes. Aquat. Bot. 34:233–266.

COOK, C. D.K . 1985. Range extensions of aquatic vascular plant species. J. Aquat. Plant Manage. 23:1–6.

——— and R. LÜÖND 1982. A revision of the genus *Hydrilla* (Hydrocharitaceae). Aquatic Bot. 13:485–504.

EPSTEIN, E. 1972. Mineral nutrition of plants: Principles and perspectives. John Wiley and Sons, Inc. New York, NY. 412 p.

HOLADAY, A. S., M. E. SALVUCCI, AND G. BOWES. 1983. Variable photosynthesis/photorespiration ratios in *Hydrilla* and other submersed aquatic macrophyte species. Can. J. Bot. 61: 229–236.

Hutchinson, G. E. 1975. A treatise on Limnology. Vol. 3. Limnological Botany. John Wiley and Sons, Inc. New York N.Y. 660 p.

Pieterse, A. H. 1981. *Hydrilla verticillata*—a review. Abstracts on Tropical Agriculture. Royal Trop. Inst., Amsterdam. 7:9–34.

Prins, H. B. A. and J. T. M. Elzenga. 1989. Bicarbonate utilization: function and mechanism. Aquat. Bot. 34:59–83.

———, J. O'Brien and P. E. Zanstra. 1982. Bicarbonate utilization in aquatic angionsperms, pH and CO_2 concentrations at the leaf surface. Pp. 112–119. *In*: J. J. Symoens, S. S. Hooper and P. Compere (Editors), Studies on Aquatic Vascular Plants. R. Bot. Soc. Belgium, Brussels.

Salvucci, M. E. and G. Bowes. 1983. Two photosynthetic mechanisms mediating the low photorrespiratory state in submersed angiosperms. Plant. Physiol. 73:488–496.

Sand-Jensen, K. 1987. Environmental control of bicarbonate use among freshwater and marine macrophytes. Pp. 99–112. *In:* Crawford, R. M. M. (ed.) Plant life in aquatic and amphibious habitats. Spec. Publ. No. 5, Br. Ecol. Soc., Blackwell Sci. Publ., Oxford.

Steward, K. K. and R. A. Elliston. 1973. Growth of hydrilla in solution culture at various nutrient levels. Florida Sci. 36(2–4):228–233.

———. 1991. Growth of various hydrilla races in waters of differing pH. Florida Scient. 54(2): 117–125.

Stumm, W. and J. J. Morgan. 1970. Aquatic chemistry. An introduction emphasizing chemical equilibria in natural waters. Wiley-Interscience. New York, NY.

Swarbrick, J. T., C. M. Finlayson and A. J. Cauldwell. 1981. The biology of Australian weeds. 7. *Hydrilla verticillata* (L.f.) Royle. J. Australian Inst. Agric. Sci. 183–190.

Florida Scient. 61(1): 1–6. 1998
Accepted: May 23, 1997

OCCURRENCE OF THE MANTA RAY, *MANTA BIROSTRIS,* IN THE INDIAN RIVER LAGOON, FLORIDA—*Douglas H. Adams*(1) *and Elena Amesbury*(2), (1)Florida Marine Research Institute, Florida Department of Environmental Protection, 1220 Prospect Ave., Suite 285, Melbourne, FL 32901 and (2)University of Central Florida, Department of Biology, Orlando, FL 32816

ABSTRACT: *The manta ray,* Manta birostris, *is occasionally observed in nearshore and offshore habitats along the Atlantic coast of Florida. This species has once been observed in a North Carolina estuary, but has not been previously recorded from other estuarine waters of the southeastern United States. This study documents three manta rays observed within the inshore waters of the Indian River Lagoon system, FL, and Port Canaveral, FL, during 1993 and 1994.*

THE manta ray, *Manta birostris* (family Mobulidae), is the largest of the batoid fishes, having a maximum disk width (DW) of at least 6.7 m and a total weight (TW) of more than 1,360 kg in the western North Atlantic (Bigelow and Schroeder, 1953) and up to 6.8 m DW and 2,000 kg TW in the Indian Ocean (Kunjipalu and Boopendranath, 1981). The species has a circumtropical distribution and in the western Atlantic ranges from New England and Georges Bank south to mid-Brazil (Bigelow and Schroeder, 1953). Along the Atlantic coast of Florida, manta rays are occasionally observed in offshore, nearshore, surf zone, and inlet habitats (Gilmore et al., 1981; D. Adams, pers. observations). This species has once been observed in the Cape Fear River estuary, NC (Schwartz, et al., 1982; Schwartz, 1995), but has not been previously recorded from other estuarine waters of the southeastern United States. This note describes three recent observations of manta rays in the estuarine waters of the Indian River Lagoon system and Port Canaveral on the east-central coast of Florida.

The Indian River Lagoon is an approximately 250-km-long estuarine lagoon system on the Atlantic coast of Florida that extends from Ponce de Leon Inlet (29°04′ N lat.) to Jupiter Inlet (26°56′ N lat.). Mean annual salinity for the lagoon is approximately 25‰ (Gilmore, 1977).

The first manta ray was observed on 28 August 1993 in Port Canaveral, Florida (28°25′62″ N; 80°36′90″ W), swimming in a U.S. Navy docking area between a docked U.S. Navy vessel and dock bulkhead. Disk width was approximately 2 m. A National Marine Fisheries Service (NMFS) M-type dart tag (No. 165705) was applied to the left pectoral fin near the mid-line of the specimen's disk. The manta ray remained near the Navy vessel for approximately 48 hr before leaving the area.

Another manta ray (FSBC 18734, Florida Department of Environmental Protection Florida Marine Research Institute Fish Collection, St. Petersburg, Florida) was observed on 12 March 1994 within the lagoon, 2 km south of Sebastian Inlet, Florida (27°49′62″ N; 80°27′79″ W). Disk width was approximately 4 m. The ray swam for 2.5 hr over seagrass flats in water 1.5

m deep. Unhealed lacerations were noted near the left orbit region and on the left pectoral fin of this specimen. Orientation and position of the wounds suggested they may have resulted from a collision with a boat propeller and skeg. Similar lacerations resulting from boat collisions have been observed on Florida manatees (*Trichechus manatus latirostris*) (Beck and Reid, 1995; Wright et al., 1995). An NMFS "M" dart tag (No. 189045) was applied to this specimen. This tag was returned later the same day from the same area by a recreational fisherman who hooked the manta ray with a conventional fishing rod and reel. The manta ray was reportedly released alive; however, the fisherman reported that the encounter had reopened one of the lacerations and that blood was trailing from the specimen as it swam away. It was not observed in this location on the following day, 13 March 1994.

A third manta ray (UF 103248, Florida Museum of Natural History Ichthyology Collection, Gainsville, Florida) was captured in a 275-m-long, 30.5-cm-mesh nylon gillnet on 22 June 1994 approximately 2 km south of Sebastian Inlet, Florida (27°49′57″ N; 80°26′18″ W), near the area where the second specimen was observed. Disk width was approximately 1.5–1.8 m. This manta ray was captured over seagrass flats where water depth was 2 m.

Manta rays have not been reported previously in the Indian River Lagoon but have been documented in the surf zone, inlet waters, and neritic zone of the Atlantic coast of Florida (Gilmore et al., 1981). Other large or related species of pelagic rays have been documented from the lagoon. A devil ray, *Mobula hypostoma* (family Mobulidae), was observed in the lagoon on 7 August 1987 about 2 km south of Sebastian Inlet, Florida (Schmid et al., 1988), near the area where two of the three manta rays were observed. Schmid and co-workers (1988) suggested that this ray may have been a waif. This also may be the case for the manta rays observed in the lagoon. The spotted eagle ray, *Aetobatis narinari* (family Myliobatidae), a large pelagic ray, is frequently observed in the southern Indian River Lagoon (Gilmore et al., 1981; Schmid et al., 1988; D. Adams, pers. observations). Schmid and co-workers (1988) indicated that there probably was a permanent population of spotted eagle rays in the lagoon; however, the species may frequently move between the lagoon and adjacent coastal waters via inlets.

All manta rays in the Indian River Lagoon were observed close (≤2 km) to oceanic inlets. The infrequent observation, or rarity, of manta rays in the Indian River Lagoon, coupled with recent observations of their proximity to oceanic inlets, suggested that individuals of this species may enter the system sporadically and remain in the estuary for only short durations.

Acknowledgments—We greatly appreciate the field assistance of D. A. Cook during the first two observations and the University of Central Florida Marine Turtle Research Group, under the direction of L. M. Ehrhart, for their assistance during the third observation. L. C. French, R. G. Gilmore, Jr., J. G. Leiby, J. F. Quinn, Jr., F. J. Schwartz, and F. F. Snelson, Jr. reviewed the manuscript and made many helpful suggestions. Technical assistance was provided by Cape Canaveral Scientific, Inc., Melbourne Beach, FL.

LITERATURE CITED

BECK, C. A. AND J. P. REID. 1995. An automated photo identification catalog for studies of the life history of the Florida manatee. Pp. 120–134. *In*: O'Shea, T. J., B. B. Ackerman, and H. F. Percival (eds.). Population Biology of the Florida Manatee. Natl. Biol. Serv. Inf. Technol. Rep. 1.

BIGELOW, H. B. AND W. C. SCHROEDER. 1953. Fishes of the western North Atlantic. Sawfishes, guitarfishes, skates, rays, and chimaeroids. Sears Found. Mar. Res., no.1, part 2. 588 p.

GILMORE, R. G., JR. 1977. Fishes of the Indian River Lagoon and adjacent waters, Florida. Bull. Fla. State Mus. Biol. Sci. 22(3):101–147.

———, C. J. DONOHOE, D. W. COOKE, AND D. J. HERREMA. 1981. Fishes of the Indian River Lagoon and adjacent waters. Harbor Branch Found. Tech. Rep. No. 41. 64 p.

KUNJIPALU, K. K. AND M. R. BOOPENDRANATH. 1981. Note on the catch of a giant ray *Manta birostris* (Walbaum) off Veraval, north west coast of India. Indian J. Fish. 1:278–280.

SCHMID, T. H., L. M. EHRHART, AND F. F. SNELSON, JR. 1988. Notes on the occurrence of rays (Elasmobranchii, Batoidea) in the Indian River Lagoon system, Florida. Florida Scient. 51:121–128.

SCHWARTZ, F. J., W. T. HOGARTH, AND M. P. WEINSTEIN. 1982. Marine and freshwater fishes of the Cape Fear Estuary, North Carolina, and their distribution in relation to environmental factors. Brimleyana 7:17–37.

———. 1995. Elasmobranchs frequenting fresh and low saline waters of North Carolina during 1971–1991. J. Aquariculture Aquat. Sci. 7:45–51.

WRIGHT, S. D. , B. B. ACKERMAN, R. K. BONDE, C. A. BECK, AND D. J. BANOWETZ. 1995. Analysis of watercraft-related mortality of manatees in Florida, 1971–1991. Pp. 259–268. *In*: O'Shea, T. J., B. B. Ackerman, and H. F. Percival (eds.). Population Biology of the Florida Manatee. Natl. Biol. Serv. Inf. Technol. Rep. 1.

Florida Scient. 61(1): 7–9. 1998
Accepted: May 27, 1997.

MANAGEMENT OF THE FLORIDA RED TIDE—REVISITED

Dean F. Martin and William H. Taft

Institute for Environmental Studies, Department of Chemistry,
University of South Florida, Tampa, FL 33620

Abstract: *A recent review of control and mitigation cirteria for red tide is reviewed, misunderstandings are corrected, and alternative points of view are presented. In particular, literature concerning marine allelopathy seems to have been neglected, criteria for an effective control agent are reviewed, and advantages of a degradable organic compound versus a non-degradable inorganic substance are considered. An attempt is made to overcome some evident misunderstandings and misconceptions that appear to exist in the literature.*

Red tide is the sudden appearance of organisms in the marine environment leading to discolored water and other phenomena. In Florida, bloom appearances are associated with the unarmored dinoflagellate *Gymnodinium breve* (a.k.a. *Ptychodiscus brevis*) that are associated with marine mortalities (fish kills), mild cases of shellfish poisoning, and asthma-like symptoms associated with aerosols. Such appearances have been noted since the 1840s along the west coast of Florida, typically from Cape Sable to north of Tarpon Springs (Rounsefell and Nelson, 1966; Steidinger, 1973). Most commonly, the outbreaks have been observed in the fall following periods of heavy rainfall, though there have been a few notable outbreaks during summer months (Steidinger et al., 1966). Outbreaks have been observed typically every three to four years.

Red tides occurring during the 1995–96 season occasioned more than typical concern. The reason for this may well have been the deaths of manatees that were thought to have been caused by intoxications from red tides. In November 1996, a planning meeting was convened at the Florida Marine Laboratory in St. Petersburg for many scientists known to have an interest in the Florida red tide problem.

At that meeting, Donald M. Anderson announced he was preparing a document (cf. Anderson, 1996) to summarize available information concerning control and mitigation of red tides, surely a formidable task and a commendable activity. We had considered the potential for management of red tide about ten years ago (Taft and Martin, 1986), and it seems timely to revisit the topic. Members of the Institute for Environmental Studies and its forerunner laboratories at USF have been concerned with aspects of red tide since the late 1960s. Previous projects included the Stream Signature Project, in which we identified characteristics of streams that emptied into the Gulf

TABLE 1. Suggested criteria for a successful red tide control agent.*

Criterion No.	Criterion
1	Should be sought in the marine environment
2	Should have a favorable log K_{ow} value
3	Should degrade naturally, but at an economically useful rate
4	Must be toxic to *Gymnodinium breve* at a low level of application
5	Must not stimulate the growth of *G. breve,* even at low levels of application
6	Should cause destroyed *G. breve* cells to clump together
7	Must not harm other marine life
8	Must be economically favorable to use
9	Must be environmentally acceptable
10	Must be . . ..

* Martin, 1980.

of Mexico above, along, and below the traditional red tide outbreak observations areas (Martin et al., 1971). Other investigations were concerned with identification of red tide toxin characteristics and predictive guides for red tides (Ingle and Martin, 1971; Kim and Martin, 1974). The last study, together with a discovery, led to concern for management over two decades ago. At that time, to discuss management, let alone use the word control, brought about much discussion over the impossibility of control, which subsequently evolved into a consideration of red tide usefulness (in analogy to the usefulness of forest fires and the usefulness of wolves). Thus, it is easy to believe we were pioneers in our concern with those factors leading to management of Florida red tides through use of chemicals. This concern, and related research, led to the consideration and enunciation of some ten criteria for a successful red tide control agent (Table 1; Martin, 1980).

The first criterion—that the control agent should be sought in the marine environment—was suggested for four reasons. The first was the recognition of the futility of a try-it-off-the-shelf approach to chemical selection which had been used during an earlier crisis of red tide and an attempt to use chemical control. During this period, Marvin and Proctor (1964) tested 4,306 chemicals with 250 successes, based upon their criterion of death at 0.04 ppm. But the cost of many was excessive, and there seems to have been no follow-up study. The second reason was based upon a consideration of the research of Pütter and others, summarized so well by Maestrini and Bonin (1981). Pütter (1907ab) was probably first to indicate the importance of algal secretion and the concentration of dissolved organic substances in seawater, though it appears that he overestimated the quantitative importance by an order of magnitude (Maestrini and Bonin, 1981). Subsequently, many others not only studied allelopathic relationships for freshwater and seawater, but a goodly number of reviews have been written on the subject. The historical treatment has been provided by Maestrini and Bonin (1981). The third reason was the consideration that if the problem was in the marine environment,

TABLE 2. Summary of APONINs from allelopathic organisms.

Organism	APONIN	Reference
Gomphosphaeria aponina	APONIN–1	Kutt and Martin (1975); Martin and Martin (1976)
Nannochloris sp	APONIN–2	Moon and Martin (1984); Martin and Martin (1987)
	ψ–APONIN*	Pabón de Majid and Martin (1983)
Nannochloris oculata	APONIN–3a, 3b	Pérez et al. (1997)

* Material was not cytolytic but induced resting stage of *G. breve*.

the ideal solution probably lay there as well. A fourth reason was the marine environment was where we discovered the first potential control agent.

Our discovery of marine allelopathy affecting *G. breve* was described two decades ago by Kutt and Martin (1975). At that time, we provided evidence that an organism produced a chemical or chemicals that affected *G. breve* by cytolysis (McCoy et al., 1979). An acronym was devised to describe such chemicals: APONIN [**AP**parent **O**ceanic **N**aturally occurring cytol**IN**]. What was evident to us, but seemingly not to others, was there could be more than one APONIN, i.e., more than one cytolytic agent produced by a single species.

The matter needs clarification: there are at least three APONINs (1, 2, and 3a and 3b, *plus pseudo-or ψ*-APONIN; Table 2). Criticism (Anderson, 1996, Steidinger, 1983) that APONIN- 1 lost 75% of its activity at the pH of sea water has no applicability to APONIN -2 or 3 or ψ-APONIN. In addition, the data referred to a 48- hour assay (Martin and Martin, 1976), time which might be enough to adversely affect the red tide organism.

A complication occurred in the identification of the responsible organism(s). APONIN-1 was associated with an organism identified as *Gomphospheria aponina* (Kutt and Martin, 1975; Martin and Martin, 1976) . As time passed, however, the culture was transformed, and it became evident later that what happened was contamination of the *G. aponina* culture by another organism that was later identified as a *Nannochloris* sp. The situation was unfortunate, but hardly unique to us: Japanese workers reported a similar experience (Maestrini and Bonin, 1981).

A second criterion (Table 1) addresses the need for a control chemical to be able to enter into the cells of *G. breve* or other target organism.. To achieve this goal, the chemical should be lipophilic. One measure of this is the K_{ow} value, the octanol-water partition coefficient: the higher the value, the more lipophilic the substance. APONIN -2 was criticized because it is hydrophobic and "thus would have to be chemically modified for use in water" (Steidinger, 1983 , cited by Anderson, 1996, p. 28). This criticism seems invalid because log K_{ow} , a measure of hydrophobicity, is inversely related to log solubility, and thus low water solubility is an asset, not a disadvantage, assuming the purpose is to have the chemical penetrate a cell wall. APONINs by definition are natural products and are delivered in the environment by organisms.

The mechanics of a delivery system becomes another issue, however, because G. breve cells are distributed through the water column during the day. Opponents of chemical control would argue that a water-soluble compound is needed for the control agent to be uniformly distributed. Possibly, however, uniform distribution of control organisms would release a useful chemical and permit control. Our past experience indicated that *Nannochloris sp.* was distributed in the culture containers (20 -L carboys, and a 400-L plastic container) with little agitation.

The wisdom of Criterion 3, concerning the degradation of a control chemical, seems evident. In addition, does one want to sweep *G. breve* from the water column and accumulate the organism and associated toxins in the sediment, perhaps to be incorporated in the food chain by benthic organisms? We believe that dispersal of toxins by destroying *G. breve* with a biodegradable APONIN is far superior to concentrating brevetoxins in the sediments.

The ideal control chemical should be active at a low level of application (Table 1, criterion 4). Related to this is a caveat that perhaps one should not report results at an early state of completion. In an amusing exercise, the amount of *crude* APONIN-1 needed to control a red tide outbreak (one square mile to a depth of one meter) was calculated (Steidinger, 1983) to be one ton. In clarification, it was noted (Martin and Martin, 1987) that with purification of chemicals, specific activity should increase, and a 10^5 enhancement of activity was described. This would change the amount of APONIN required from one ton to two- tenths of a pound. And one might hope for additional enhancement of activity upon further purification. Given a reasonable compound, e.g., APONIN- 3a or 3b (Pérez et al., 1997), the synthesis would be easily effected from comparatively cheap materials, e.g., methanol and a fatty acid.

On the other hand, it is equally plausible to use the organism as the delivery system for a control chemical. The advantages of this were described in some detail previously (Taft and Martin, 1986). Moon and Martin (1979) noted the ability to store concentrated cells at 4° C and to achieve regeneration. Obviously, the successful agent should not stimulate growth of *G. breve,* even at low conentrations of agent (Criterion 5). It would be useful, though not required if the agent would assist agglomeration of cell debris from destroyed *G. breve* to minimize release of brevetoxin (Criterion 6).

Criterion number 7, that the APONIN selected must not harm marine life is obviously important. What should be equally obvious is that it takes time and resources to perform such tests. The amount of effort expended on testing one material was formidable, but we believe interesting results were obtained. For example, when one APONIN-producing organism was tested against brine shrimp, it was found that the brine shrimp thrived in the presence of the organisms (they consumed it) during the period of the experiment

(Eng-Wilmot and Martin (1979). In addition, brine shrimp died in the presence of *G. breve,* and thrived in the presence of *Nannochloris* sp. (McCoy et al., 1979). Finally, bioassay acute toxicity tests used *Nannochloris* sp., a possible control agent, to study the effect on three bioassay species, *Cyprindon variegatus, Mysidopsis bahis,* and *Neanthes arenaceodentata.* Algal cell concentrations were far in excess of what might occur in the Gulf of Mexico ($3 \times 10^6 - 25 \times 10^9$ cells/L), and no toxic effects were observed (Taft and Martin, 1986).

In addition, it may be possible to obtain useful information through cheaper screening. For example, one can show that "the cure is not worse than the disease"in a fairly simple, but effective way. It was possible to demonstrate that *G. breve* toxins cause smooth muscle contraction that is responsible for the asthma-like symptoms that are observed during red tide outbreaks (Asai et al., 1982) for canine tracheal tissue (and subsequently verified for human tracheal tissue). On the other hand, APONIN-2 from *Nannochloris* sp. had no effect at similar levels (Sakomoto, et al., 1983). The implications are evident that were APONIN-2 to be used as a control agent, any aerosols would not have an adverse effect (the cure would not be worse than the disease).

The fact remains, however, and clearly more evident to those of us who teach or are involved in toxicology, how very expensive and important is the cost of doing appropriate bioassays. Marine allelopathy with APONINs or *pseudo*-APONINs would seem to satisfy most of the criteria listed in Table 1, though there is room for disagreement and improvement in regard to which APONIN and which APONIN-releasing organism might be preferable for a given situation.

With *Nannochloris sp.,* the growth constant was measured as a function of salinity (Martin and Gonzalez, 1978), and the observed maximum was 28 ppt, as compared with 32–33 ppt for *G. breve.* In addition, the the rate of synthesis of APONIN-2 correlated positively and significantly with the rate of DNA synthesis. The latter was biphasic and was a minimum at a growth constant, $k_e = 0.95$ day^{-1} . This information suggests that APONIN-2 was produced continuously during the log-growth phase, but that the generation of APONIN-2 was optimal in the neretic zone where the growth of *G. breve* is favored (Martin and Gonzalez, 1978). Similar information is not presently available for APONIN-1 or APONIN-3.

Finally, the tenth criterion may be most significant—the correct control agent must depend upon the circumstances and kind of red tide.

The study of management of Florida red tide outbreaks has been a long, interesting process. How fruitful it has been must await the verdict of history. Progress in science depends upon the willingness of scientists to present results and to take advantage of useful and valid suggestions and to be responsive to valid criticisms.

ACKNOWLEDGMENTS—We appreciate the helpful comments of Donald M. Anderson and Ralph E. Moon. Barbara B. Martin served as Consulting Editor.

LITERATURE CITED

ANDERSON, D. M. 1996. Control and mitigation of red tides. December 4. Manuscript prepared for Project START (Solutions to Avoid Red Tide), Sarasota, FL. 59 pp.

ASAI, S., J. J. KRZANOWSKI, W. H. ANDERSON, D. F. MARTIN, J. B. POLSON, R. F. LOCKEY, S. C. BUKANTZ, AND A. SZENTIVANYI. 1982. Effects of the toxin of red tide, *Ptychodiscus brevis*, on tracheal smooth muscle (A possible new asthma-triggering mechanism). J. Allergy Clin. Immunol. 69:418–428.

ENG-WILMOT, D. L. AND D. F. MARTIN. 1979. Short term effects of aponin and [*Nannochloris* sp.?] in unialgal and mixed cultures with *Gymnodinium breve* on *Atemia salina*. J. Pharm. Sci. 68:963–966.

INGLE, R. M. AND D. F. MARTIN. 1971. Prediction of the Florida red tide by means of the iron index. Environ. Lett. 1:69–74.

KIM, Y. S. AND D. F. MARTIN. 1974. Interrelationship of Peace River parameters as a basis of the iron index. Wat. Res. 8:607–616.

KUTT, E. C. AND D. F. MARTIN. 1975. Report on a biochemical red tide repressive agent. Environ. Letters 9:195–208.

MAESTRINI. Y. AND D. J. BONIN. 1981. Allelopathic relationships between phytoplanktonic species. Pp. 323–338. *In*: PLATT, T. (ed.) , Physiological Bases of Phytoplankton Ecology. Canad. Bull fish. Aquat. Sci. 210.

MARTIN, B. B. AND D. F. MARTIN. 1976. Aponin, a cytolytic factor toward the red tide organism, *Gymnodinium breve*. J. Environ. Sci. Health A11:613–622.

——— AND D. F. MARTIN. 1987. Enhanced activity of a red tide (*Ptychodiscus brevis*) cytolytic fraction from the green alga, *Nannochloris sp.* Environ. Sci. Health A22:457–462.

MARTIN, D. F., M. T. DOIG, III, AND R. H. PIERCE, JR. 1971. Distribution of Naturally Occurring Chelators (Humic Acids) and Selected Trace Metals in Some Florida Streams, 1968–1969. Fla. Dept Nat. Resources Prof. Pap. Ser. 12.

——— AND M. H. GONZALEZ. 1978. Effects of salinity on synthesis of DNA, acidic polysaccharide, and growth in [*Nannochloris sp.*]. Wat. Res. 12:951–955.

———. 1980. Red tide, red blood. Lecture presented to Philadelphia Section, American Chemical Society, Philadelphia, March 20.

MARVIN, K. T. AND P. R. PROCTOR, JR. 1964. Preliminary results of the systematic screening of 4,306 compounds as red tide toxicants. U.S. Fish Wild. Serv. Data Rpt 2

MCCOY, L. F., JR., D. L. ENG-WILMOT, AND D. F. MARTIN. 1979. Isolation and partial purification of a red tide (*Gymnodinium breve*) cytolytic factor(s) from cultures of *Gomphosphaeria aponina*. J. Agri Food Chem. 27:69–74.

MOON, R. E. AND D. F. MARTIN. 1979. Potential management of red tide blooms. Treatment with concentrated frozen [*Nannochloris* sp.?] cultures. J. Environ. Sci. Health A14:195–199.

——— AND D. F. MARTIN. 1984. Studies of allelopathic substances from a marine alga Pp. 381–386. *In:* Thompson, A.C.(ed.) Chemistry of Allelopathy, ACS Symp. Ser. 268, American Chemical Society, Washington, D.C.

PABÓN DE MAJID, L. AND D. F. MARTIN. 1983. Induction of sessile stage formation of the red tide organism, [*Gymnodinium breve*], by material elaborated by [*Nannochloris* sp.] Microbios Letters 22:59–65.

PÉREZ, E., D. F. MARTIN, AND W. SAWYERS. 1997. Evaluation of allelopathic materials produced by *Nannochloris oculata* . Florida Scient. 60(SP1):24.

PÜTTER, A. 1907a. Die Ernährung der Wassertiere. Z. Allg. Physiol. 7:283–320.

———. 1907b. Der Stoffhaushalt der Meeres. Z. Allg. Physiol. 7:321–368.

ROUNSEFELL, G. A. AND W. R. NELSON. 1966. Red-tide research summarized to 1964, including an annotated bibliography. U.S. Fish Wildl. Serv. Spec. Sci. Rep., Fish No. 535: 85 pp.

SAKOMOTO, Y., J. J. KRZANOWSKI, R. F. LOCKEY, AND D. F. MARTIN. 1983. Effect of aponin from cultures of the green alga *Nannochloris sp.* on canine tracheal smooth muscle. J. Environ. Sci. Health A18:721–728.

STEIDINGER, K. A. 1973. Phytoplankton ecology:a conceptual review based upon eastern Gulf of Mexico research. Crit. Rev. Microbiol. 3:49–68.

———. 1983. A re-evaluation of toxic dinoflagellate biology and ecology. Prog. Physiol. Res. 2:147–188.

———, J. T. DAVIS, AND J. WILLIAMS. 1966. Observations of *Gymnodinium breve* Davis and other dinoflagellates. Pp. 9–15 *In*: Observations of an Unusual Red Tide. A Symposium. Prof. Pap. Ser. 8. Florida Board of Conservation, Marine Laboratory, St. Petersburg, FL.

TAFT, W. H. AND D. F. MARTIN. 1986. The potential for managing a red tide. J. Environ. Sci. Health A21:107–127.

Florida Scient. 61(1): 10–16. 1998
Accepted: June 27, 1997.

ENHANCED SOLUBILITY OF SODIUM FLUOROSILICATE SCALE BY MAGNETIC TREATMENT

CHUHUA WANG, ROBERT F. BENSON, AND DEAN F. MARTIN

Institute for Environmental Studies, Department of Chemistry,
University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620-5050

ABSTRACT: *Sodium fluorosilicate, a by-product of the production of phosphoric acid, is a nuisance material because of the tendency to build up in pipes and the need to remove the material from pipes. Samples of scale from the industry were analyzed and were tested in the presence and absence of magnetic fields (1200 and 2000 gauss). Enhanced solubility was noted in the presence of a magnetic field. The effect is ascribed to an increase in entropy as a result of the field, and the entropy increase results in an increase in the solubility of the scale. At room temperature, the solubility of fluorosilicate scale was 1.70g/100g, and at 50° C in the presence of a magnetic field it was increased by about 25–28%.*

EXCESSIVE metallic impurities in phosphoric acid have caused economic and operating penalties on the industry. Removal of these unwanted metals would reduce post precipitation in the acid, reduce or eliminate scaling in the system, and make it possible to achieve a diammonium phosphate (DAP) grade of 18-46-0 without the addition of supplementary nitrogen (Lloyd, 1995). The nuisance metals include iron, aluminum, and magnesium.

Progress is being made. A patent has described a method for removing magnesium from phosphate ore (Benson and Martin, 1996), and magnetic treatment offers promise for managing one and perhaps two of the remaining nuisance metals.

Chemical technology has used magnetism for separations, but the examples have typically involved ferromagnetism or paramagnetism (Hirschbein et al., 1982; Kolm et al., 1975). An early application of of high-gradient-magnetic separation (HGMS) involved removal of colored impurities from kaolin clay. Discoloring particles that were paramagnetic with small diameters (ca 1 mm) were removed with HGMS to yield beneficiated kaolin clay that was used by the paper industry to enhance brightness (Price and Abercrombie, 1979).

Removal of nuisance impurities by diamagnetism, e.g., minimization of calcium carbonate scale, has been used for over a century (France and Cabel, 1890). A patent awarded to Moody (Moody, 1966) was the basis of one firm that specializes in magnets for removal of scale. Some major firms have controlled scale and corrosion in cooling tower loops using magnetic water treatment (Fryer, 1995; Baker and Judd, 1996*)*, but the basis of the success is controversial.

One basis of controversy was allegedly the absence of scientific theory to serve as a basis for such treatments (Fryer, 1995; Baker and Judd, 1996). Not all reviewers agree that a successful theory is absent (Benson et al., 1997). Benson and co-workers (Benson et al.,1994) examined the effect of diamagnetism on suspensions of magnesium hydroxide and calcium carbonate, which served as model compounds. Their hypothesis was that imposition of a magnetic field of suitable strength on a diamagnetic substance results in an increase in entropy. For suspended solids involved, this was reflected in enhanced solubility. The experimental results (enhanced pH of the suspensions) were in accord with the hypothesis (Benson et al., 1994). The system can be understood better, perhaps, in terms of the van Vleck equation (Benson et al., 1998).

Antiscale magnetic treatment (AMT) has been reported as being effective in numerous instances (Baker and Judd, 1996; Benson et al., 1997; Carpenter, 1991). It reduces scale deposition. It removes existing scale or produces a softer and less tenacious scale in the instance of calcium carbonate. It appears to be most effective for scale suspension in systems with heated surfaces and recirculated water (Tye, 1993). Large savings in energy, cleaning time and chemicals, and process downtime costs have been reported from the installation of magnetic water conditioners in real systems (Fryer, 1995; Baker and Judd, 1996; Benson et al., 1997).

Not all experiences are successful (Fryer, 1995; Baker and Judd, 1996), possibly because of lack of attention to critical detail (Benson et al., 1997). Iron and silica concentrations are significant (Benson et al., 1997) and must be controlled for success in AMT. Grimes (1988) reported a correlation between the calcium carbonate crystal size and the magnetic field strength, but AMT with calcium sulfate scale appeared to reduce crystal size and favor aggregation. Thus the anion may influence the effectiveness of AMT, according to Higashitani and co-workers (1993).

Sodium fluorosilicate scale is a nuisance material in the production of phosphoric acid. It is a sparingly soluble salt and deposited inside on the walls of pipes. Currently, a portion of the phosphoric acid plant must be shut down for the removal of the scale, and this is a nuisance and costly in terms of down time. The scale is contaminated with iron and other impurities that prevent its sale as a fluoride source.

We present here results of the use of diamagnetism for enhancement of solubility of sodium fluorosilicate scale from a phosphoric acid plant.

MATERIALS AND METHODS—*Materials*—Chunks of scale (May, 1995, weighing about 6.0 kg) from a phosphoric acid plant were provided by Mr. J. Harold Falls, Chief Chemist, CF Industries, Plant City, Florida. The samples consisted of layers of white and gray materials. The scale lumps were washed in water, then washed as clean as possible in distilled water, dried on paper towels, and allowed to air dry. Samples were crushed into three sizes: small rocks were produced by hitting the samples (in clean plastic) with a hammer. The small rocks were subjected to a Braun jaw crusher (Chipmunk model), to produce pebbles. The latter were placed in an attrition mill ("coffee grinder") to produce fine material that passed through a size

TABLE 1. Percent composition and magnetic susceptibilities for scale samples.

	Per Cent Composition				Magnetic susceptibility
Sample	Na	Si	F	Fe, ppm	10_6 (X^g)
Na_2SiF_6 (theoretical)	24.5	14.9	60.6		
Sample 1(5/105)	22.02	13.46	62.3 ± 1.3	47*	−0.31**
Sample 2 (12/105)					
white portion:			57.7 ± 1.4	30	−0.20
gray portion:			310.5 ± 1.3	1610	+0.0410

* White portion.

** Gram susceptibility, cgs units.

50 mesh. The ultra fine was (mainly) the result of the simple hammer treatment. The waste was the material that was used to clean out the attrition mill and was set aside for future use.

A second sample of white scale (Dec, 1995) was separated and purified by removing the gray layer and polishing the white layer surface. White scale was used for the investigation of magnetic treatment on scale suspension.

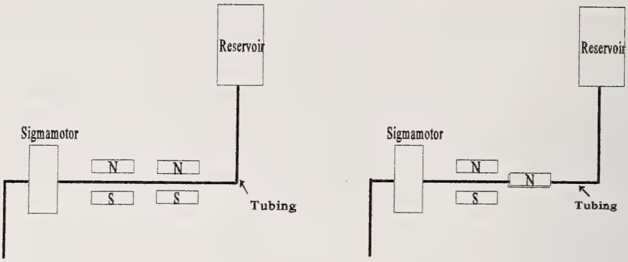
Analytical methods—X-ray fluorescence—Material was mounted, as a representative crystal, and subjected to EDAX (energy dispersive x-ray) fluorescence in the Electron Microscopy Laboratory (USF College of Engineering). Using 20 kV, 40.0 degrees, and VFS = 4096, the elements detected were (atom %, weight %) sodium (40.7, 35.6), silicon (54.7, 58.5), phosphorus (3.0, 3.5), calcium (0.45, 0.610), sulfur (0.23, 0.28), and potassium (0.91, 1.4).

Fluoride analysis—About 0.5 g of powdered scale was dissolved in 200 mL of deionized water using a Cole-Parmer (model 8845-3) ultrasonic cleaning bath. Subsequent dilutions were made so that the activity of fluoride ion was in an optimum range (10–100 ppm) for measurement by an ion-selective method (Eaton et al., 1995). Two standard fluoride ion solutions (10 and 100 ppm, prepared from Fisher 1000 ppm fluoride standard) were used for calibration. Measurements were made using a fluoride ion-selective electrode (Fisher 13-620-522) and an Orion silver-silver chloride double junction reference electrode (model 100-02) attached to an Orion expandable ion analyzer (model EA 1020). Exactly 25.0 mL of sample and 25.0 mL of buffer were used, and the fluoride activity was measured. The Na and Si analyses were performed by SGS Commercial Testing & Engineering Co., Tampa, FL (Table 1).

Iron analyses—Certain samples could not be measured reliably by atomic absorption spectrometry because of a high concentration of scale (saturated solutions), and the relative standard deviation was high at the 1 ppm iron level, so a thiocyanate colorimetric method (Marczenko, 1986) was used instead. A 2- g. sample of scale was digested with aqua regia ($3HCl:HNO_3$, v/v) and diluted to 100 mL at pH = 1 ± 0.1. These solutions were either measured directly or were measured after concentration by evaporation if the iron content was too low to be measured accurately. The measurable iron concentration for the thiocyanate method was 3–5 ppm. For those solutions of iron concentration less than 1 ppm, the concentration process was needed.

Magnetic susceptibility was measured on the magnetic susceptibility balance (Johnson Matthey Inc., 1401 King Road, West Chester, PA 110380). The unit (Woolcock and Zafar, 1992) had been calibrated using $HgCo(SCN)_4$ (Bünzli, 1979) to be able to obtain the gram susceptibility (χ_g).

Magnetic treatment—Four methods were used. With *method a,* a 2-L reservoir was placed 8 m above the inlet of a hydrocyclone and the scale suspension was mechanically stirred. A PVC (1-in, 2.54 cm i.d.) pipe was used to connect reservoir and hydrocyclone, and the scale suspension was passed through the magnetic field 5 times. Overflow solid and underflow solid were separated



parallel perpendicular

FIG. 1. Schematic representation of magnetic treatment.

and were dried in a 75°C oven. The pH of the suspension solution was measured (Beckman Expandomatic® SS-2). Both samples of scale were investigated for the iron removal. With *method b* and *method c,* the reservoir was placed 1 m above inlet of the hydrocyclone and the scale suspension was magnetically stirred. Reservoir and hydrocyclone were connected by Tygon® tubing 3/8-in (9.5 mm) i.d. Two pairs of magnets (1200 gauss each) were placed on the outlet of the reservoir in method b and one magnetic set with 2-in i.d. pipe was applied in method c. The scale suspension was passed through the magnetic field once or 5 times. In *method d,* a magnetically stirred suspension of 100g of scale in 1.5 L of 28.5% phosphoric acid was passed through Tygon® tubing (3/8 in, 9.52 mm id) 21 ft (6.4 m) long using a Sigmamotor ZERO-MAX® finger pump (model T-6S) so that no liquid came in contact with metal (Fig. 1). Treatments were done at 23°, 50° and 90° C. A volumetric flow rate of 20.6 mL/sec and a fluid flow velocity of 17.5 m/min was used with 3 min. required for the fluid to complete a cycle. For recirculation, the treated suspension was passed through a magnetic field 10 times. Two different placements of the magnets were used (perpendicular and parallel, Fig 1).

With all methods, the control and test experiments were done under the same conditions, except a magnetic field was not involved with the control experiments.

Wet sieving process—Aqueous suspensions of scale were sieved completely by sieves with mesh sizes of 18, 35, 60,120, and 230. These correspond to openings of > 1.0, 0.5, 0.25, 0.063, and <0.063 mm, respectively The largest particles were first separated using the 18 mesh sieve, and collecting the suspension that passed though in a clean plastic bucket. The process was repeated using successively smaller sizes. The remainder of the suspension containing the finest particles was allowed to stand for five hours, when the suspension was collected by careful decanting. All five fractions were dried to constant weight in an oven at 75° C. Pertinent calculations (total suspended solids, fraction weight and weight percent of each fraction) were made using these data. Sieving phosphoric acid suspension of scale required a modification of the procedure. First, scale suspensions were allowed to stand for ten hours because of the viscosity and density of the phosphoric acid solution. Next the 1500 mL of phosphoric acid solution was decanted, and the scale was resuspended in one liter of water before the fractionation was started. After fractionation, the five fractions were rinsed with water (500 mL) to remove any phosphoric acid residue. Samples were then dried as before.

RESULTS AND DISCUSSION—*Characterization of scale*—Properties of the scale obtained from a phosphoric acid plant are summarized (Table 1). Two samples, obtained at six-month intervals have similar fluoride content. The analyses are consistent with sodium fluorosilicate with impurities of iron and

TABLE 2. Scale solubility in 28.5% phosphoric acid at elevated temperature.*

Method**	Cycles	Magnet field, gauss	t (°C)	Control g/100g	Treated (g) g/100g	Difference (%)$_+$
Parallel	1	1200	90	1.41	1.47	4.26
Perpend.	1	2000	90	1.41	1.57	11.3
Parallel	10	1200	50	1.05	1.32	25.7
Perpend.	10	2000	50	1.05	1.35	28.6
Parallel	10	1200	23	1.410	1.55	4.0
Perpend.	10	1200	23	1.410	1.56	4.7
Perpend.	1	1200	23	1.17	1.28	9.4
Perpend.	1	2000	23	1.17	1.61	37.6
Perpend.	1	2000	23	1.17	1.63	39.3

* Initial total scale weight is 100.0 g with fraction of +18: 5.0 g; −18/+35: 40.0 g; −35/+60: 20.0 g; −60/+120: 10.0 g; −120/+230:10.0 g; −230: 15.0 g. The solid was collected from suspension (1.5 L of solvent) by decanting phosphoric acid and washed by water. Solid scale was dried in a 75°C oven for 2 days; ** Method, magnets arranged parallel or perpendicular (perpend.) to each other. Difference (%)$_+$ = (test–control)/control; Difference (%) = (treated–control)/control × 100.

other transition metals. The material crystallized as a mixture of white and gray crystals, which could be separated by hand. The gray material contained more iron and was paramagnetic: the white crystals contained considerably more fluoride, much less iron and was diamagnetic.

Effect of magnetic treatment on scale solubility—The problem of trying to prevent scale formation is more challenging for sodium fluorosilicate scale than for calcium carbonate scale because of the magnitude of the magnetic susceptibilities. The observed value for sodium fluorosilicate was $\chi_g = -0.31 \times 10^{-6}$ c.g.s. units (Table 1), whereas the reported value for calcium carbonate is only slightly greater ($\chi_g = -0.382 \times 10^{-6}$ c.g.s.) (Weast, 1980). But both substances should be affected about the same in practice.

In all treatments, the solubility of sodium fluorosilicate scale in water was increased in the presence of a magnetic field, compared with the control. The same was true of the solubility of scale in 28% phosphoric acid (Table 2). Analysis of variance (ANOVA) showed a significant difference in scale solubility. For small particles, e.g., −230 mesh scale (<0.063 mm), change in scale solubility in water with a five-cycle run in a magnetic field was more significant than a one-cycle treatment (Table 2). The change in solubility with size is indicated in a bar histogram (Fig. 2), which shows that for the treated samples, the size distribution shifted in favor of smaller particles, most notably 0.25–0.50 mm (35–60 mesh).

The change in solubility of scale in phosphoric acid (28%) is presumably due to the increase of scale entropy, S, and destabilization of the sodium fluorosilicate lattice under the magnetic field. Magnetic effects on solubility were also investigated at higher temperatures, e.g., 50° C and 100° C (Table 2) These results show the effect of a magnetic field on scale solubility at high temperature is more significant than that at room temperature. Since $\Delta S > 0$ for scale solubility, a higher temperature has a greater value for $T \cdot$

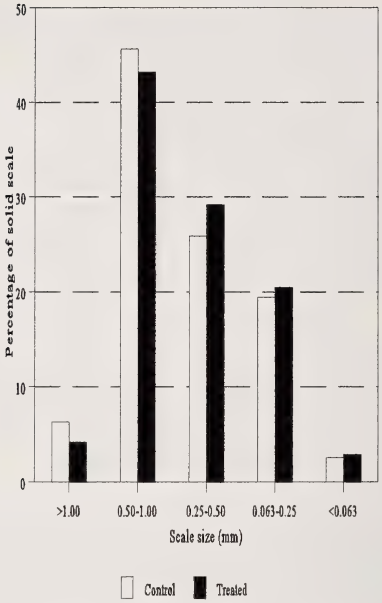


FIG. 2. Scale-size distribution with magnetic treatment of scale in 28% phosphoric acid at 50° C for 10 cycles with a perpendicular configuration (method d).

ΔS and makes free energy change, ΔG, more negative (since thermodynamically, $\Delta G = \Delta H - T \cdot \Delta S$), and as a consequence, scale becomes more soluble in phosphoric acid. A similar result was observed with water.

Since $\Delta S_{test} > \Delta S_{control}$ in the treatment, temperature affects solubility to a greater extent in a magnetic field than in absence of the field (Table 3). For larger scale (−18/+35 mesh), the solubility change for 5-cycle run was 1.25% (50° C) and 4.2% (100° C) (This may be compared with 0.16 − 1.16%, 25° C). Treatment at 100° C was more effective than that at 50° C and 25° C. For 60–120 mesh, the solubility difference was 1.64% at 50° C, compared with 0.86% at 25° C, Table 3).

An increase in time spent in a given field strength resulted in enhanced solubility. Comparing a 1-cycle run with a 5-cycle run, the solubility difference was greater for a 1-cycle run magnetic treatment for 18–35 mesh scale, and −230 mesh scale (2.1% *vs* 0.5% for −230 mesh, and 8.108%, 5.08% *vs* 4.2% for 18–35 mesh, Table 3). There is a kinetic mechanism that under magnetic field, scale is dissolved in water faster than in absence of the field. For a 1-cycle run treatment, the equilibrium has not been reached and scale solubility depended on the rate of transition from solid scale to aqueous solution. In a magnetic field, the transition rate is faster, and more solid scale is dissolved compared with the control system. After a 5-cycle run, the system is close to equilibrium, and more solid scale is dissolved and the scale solubility difference between test and control is less than the

TABLE 3. Scale solubility in water with magnetic field and without magnetic field.

Exp.	Scale size mesh	Method	Cycles	T° C	Input g	Control (g)	Treated (g)	Change* (%)
1	−18/+35	a	5	25	100	81.2	79.0	2.0
2	−35/+60	a	5	25	100	80.1	78.6	1.5
3	−60/+230	a	5	25	80	49.7	42.8	8.6
4	−230	a	5	25	70	37.14	36.62	0.7
5	−18/+35	b	5	25	50	39.76	39.18	1.16
6	−18/+35	b	5	25	50	40.56	40.48	0.16
7	−120/+230	b	5	25	50	39.39	38.50	1.79
8	−230	b	1	25	50	39.45	39.39	0.12
9	−230	b	5	25	50	39.82	39.66	0.30
10	−230	b	5	25	50	39.17	38.82	0.69
11	−120/+230	c	5	25	50	39.77	39.59	0.37
12	−230	c	1	25	50	40.13	39.32	1.62
13	−230	c	5	25	50	40.62	39.41	2.41
14	−35/+60	c	5	25	50	39.63	39.61	0.03
15	−60/+120	c	5	25	50	39.05	38.62	0.86
16	−18/+35	c	5	100	50	19.38	17.28	4.2
17	−18/+35	c	1	100	50	28.75	24.26	8.98
18	−18/+35	c	1	100	50	22.67	20.14	5.08
19	−18/+35	c	5	50	50	30.62	30.00	1.25
20	−35/+60	c	1	100	50	18.40	18.11	0.58
21	−60/+120	c	5	100	50	30.12	29.30	1.64
22	−230	c	1	100	50	37.47	36.42	2.1
23	−230	c	5	55	50	34.77	35.01	−1.96

* Change (%) = $(W_{control} - W_{treated}) \times 100\%/W_{input}$; Scale was suspended in 1.5 liter of water.

difference in the one-cycle run process (8.108 % for 1 cycle *vs* 4.20% for 5 cycle, 18–35 mesh, at 100° C, Table 3). At high temperature (100° C), scale is dissolved faster, and it takes less time to attain equilibrium compared with the process at room temperature. However, at room temperature, the difference in solubility between test and control samples after a 5-cycle run was more significant than that after a one-cycle run process (2.41% *vs* 1.62%, for −230 mesh, in method c; 0.30% *vs* 0.12%, for −230 mesh, in method b Table 3).

In summary, the presence of a magnetic field enhances the solubility of sodium fluorosilicate, and one may expect that in practical terms, there would be reduced tendency for this material to condense on pipes, particularly curved or rounded pipes. Another implication of our observations is that one may expect that given enhanced solubility of the fluorosilicate scale, the material would precipitate at a more convenient stage, i.e., in a large holding tank that would be more accessible than a 4–6 inch (10.2–15.2 cm) pipe. One problem is the presence of iron, which reduces the effectiveness of diamagnetic treatment (cf. Table 1 in Benson et al., 1997).

The process we have used, thus, would not eliminate scale, but it would mitigate against its obvious inconvenience of formation in pipes. The effect persists for some period of time (so-called "memory effect") before equilibrium is restored (Reimers, et al., 1992). Magnetic treatment would shift scale formation to an open area where it could be filtered off more conveniently and more economically.

We believe that these experiments form a sound theoretical and practical basis for future efforts to manage scale in phosphoric acid plants. This could be achieved through the judicious placement of suitable magnets so that scale instead of forming in inconvenient locations (pipes, especially bent pipes and on filter cloth) would be transported to a more convenient location for separation. In addition, magnetic treatment schemes studied here have implications for removing iron through association with fluorosilicate scale.

ACKNOWLEDGMENTS—We are grateful for the financial assistance of the Florida Institute of Phosphate Research through contract #104-01-116, and we appreciate the helpful comments of G. Michael Lloyd, Jr. We appreciate the loan of magnets by Roland K. Carpenter, President, AquaMagnetics® International, Inc.

LITERATURE CITED

BAKER, J. S. AND S. J. JUDD. 1996. Magnetic amelioration of scale formation. J. Water Res. 30: 247–260.

BENSON, R. F., B. B. MARTIN, D. F. MARTIN, AND R. K. CARPENTER. 1994. Management of scale deposits by diamagnetism. A working hypothesis. J. Environ. Sci. Health. A29:1554–1564.

——— AND D. F. MARTIN. 1996. Method for exchange based leaching of the carbonates of calcium and magnesium from phosphate rock. U.S. Patent 5,500,193.

———, R. K. CARPENTER, B. B. MARTIN, AND D. F. MARTIN. 1997. Using magnetic fields to prevent scale. Chemtech 27(4):34–39.

——— AND CO-WORKERS .1998. Unpublished manuscript

BÜNZLI, J. C. G. 1979. Comment on the use of $HgCo(NCS)_4$ as a susceptibility standard. Inorg. Chim. Acta 36:L413-L414.

CARPENTER, R. K. 1991. Magnetic treatment. Today's alternative. Paper presented at 1991 National Association of Corrosion Engineers. Maracaibo, Venezuela, Nov. 20–22.

EATON, A. D., L. S. CLESCERI, AND A. E. GREENBERG (eds). 1995. Standard Methods for the Examination of Water and Wastewater(17th eds.). American Public Health Association. Washington, D.C.

FRANCE, A. B. AND S. G. CABELL. 1890. U.S. Patent 438,579.

FRYER, L. 1995. Magnetic Water Treatment. A Coming Attraction? Tech. Update TU-95–7. E Source Reprints Service, 1033 Wealnut Street, Boulder, Colorado. 21 pp.

GRIMES, S. M. 1988. Magnetic field effect on crystals. Tube Int. March, pp 111–118.

HIGASHITANI, K., A. KAGE, S. KATAMURA, K. IMAI, AND S. HATADE. 1993. Effects of magnetic field on formation of $CaC0_3$ particles. J. Coll. Int. Sci. 156:90–95.

HIRSCHBEIN, B. L., D. W. BROWN, AND G. M. WHITESIDES. 1982. Magnetic separations in chemistry and biochemistry. Chemtech 12:172–179.

KOLM, H., J. OBERTEUFFER, AND D. KELLAND. 1975. High gradient magnetic separations. Sci. Am. 233(5):46–54.

LLOYD G. M., JR. 1995. Report to the Board of Directors, Florida Institute of Phosphate, Bartow, FL.

MARCZENKO, Z. 1986. Separation and Spectrophotometric Determination of Elements. Halstead Press, New York, NY.

MOODY, D. L. 1966. U.S. Patent 3,228,878.

PRICE, C. R. AND W. F. ABERCROMBIE. 1979. Practical aspects of high gradient magnetic separators. Pp. 14–15 *In:* Liu, Y. A. (ed.) Industrial Applications of Magnetic Separation, IEEE, New York, NY.

Reimers, R. R., M. Shariat, R. K. Carpenter, and T. G. Akers. 1992. The role of chemical constituents and their effects on scale inhibition following magnetic treatment. Report from the Department of Environmental Health Sciences, School of Public Health and Tropical Medicine, Tulane University, New Orleans, LA.

Tye, A. 1993. The magnetic treatment of water to prevent scaling. Resource 1, 25–26.

Weast, R. C. 1980. CRC Handbook of Chemistry and Physics. CRC Press, Boca Raton, FL, p. E-125.

Woolcock, J. and A. Zafar. 1992. Microscale techniques for determination of magnetic susceptibility. J. Chem. Educ. 69:A176-A179.

Florida Scient. 61(1): 17–25. 1998
Accepted: July 9, 1997.

Environmental Chemistry

ANALYSIS OF SELENIUM: AN ANNOTATED BIBLIOGRAPHY

EILEEN PÉREZ(1,2), GREGORY S. CORBETT(2), CHRISTOPHER J. COSTON(1,2),
MARIA T. GALLARDO(1,2), JAMES D. HAYES(2), AND DONGXIN WANG(2)

(1) Institute for Environmental Studies, Department of Chemistry,
University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620;
(2) Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, FL 33620

ABSTRACT: *An annotated bibliography is given of the analyses of selenium developed in the last four years. The methods of analyses include spectrophotometry, voltammetry, atomic absorption, and electrophoresis, among others. Most determine total selenium, a few determine inorganic selenium [Se(IV), Se(VI)] and organic selenium (selenocystine, selenomethionine).*

ANALYSIS of selenium has become increasingly important because of the significance of the element in nutrition, as a cancer-fighting agent (Wendel, 1988), and as an antioxidant (Wendel, 1988). This metal is an essential trace element. It occurs naturally in essentially all soils and biological materials with quantities varying from parts per billion to a few percent (Gilon and Potin-Gautier, 1996). Selenium in the diet is acquired from animals and plants and is dependent on the species and the selenium soil content (MacLeod et al., 1996), but there is a narrow range between its essential and its toxic levels.

Several cases regarding selenium deficiency include the Keshan disease and the Kashin-Beck's disease. Both have occurred in the People's Republic of China. The former consists of acute or chronic episodes of heart disorder characterized by cardiogenic shock and/or congestive heart failure (Ge and Yang, 1993). The latter is an endemic osteoarthropathy characterized by general weakness followed by joint stiffness and pain (Ge and Yang, 1993). Low selenium intake has been correlated with the high mortality rates from coronary heart disease among the Finns (Salonen, 1982; Virtamo et al., 1985) and is the cause of muscular degeneration in domestic animals in Finland (Spallholz et al., 1981). To overcome these problems, the Finns add selenium to the fodder (Spallholz et al., 1981). Another incident regarding low selenium and domestic animals occurred in the Florida Everglades where cattle grazing on St. Augustine grass growing on peaty muck soil developed anemia (Blair-West and Denton, 1984).

At the other end of the spectrum is the "devil's disease", a form of selenium poisoning in livestock that includes loss of hair and hoofs, staggering gait, swelling, suppuration and death (Rosenfeld and Beath, 1964;

Klayman and Gunther, 1973). The cause is attributed to ingestion of seleniferous plants ("loco weed"). Recorded occurrences of this disorder in North and South Dakota date back to 1857, and were prominent in the 1930s. In South Dakota, several cases of chronic dermatitis apparently caused by the ingestion of seleniferous foods were reported (Lemley and Merriman, 1941). In 1983 the selenium levels at the Kesterson reservoir, San Joaquin Valley, California, were associated with toxic effects on waterfowl and other birds (Gilliam, 1989). In 1984, 40% of the nests checked on the refuge had at least one dead embryo, and one in five had at least one embryo or chick with missing eyes, beaks, wings, legs or other gross deformities (Steinhart, 1985).

The study of the chemical species of selenium is very important because it can render more information concerning the toxicity and bioavailability of the element. Following is an annotated bibliography of the methods of analyses of selenium developed within the last four years. The list is not exhaustive, but every effort was made to include a range of different techniques. Table 1 summarizes pertinent information for each bibliography. The number in the table refers to the bibliography number.

1. Amin, A. S. and M. N. Zareh. 1996. Xylenol orange as a new reagent for the colorimetric determination of selenium and tellurium. Anal. Lett. 29:2177–2189.

Xylenol orange was used for the spectrophotometric determination of selenium. Xylenol orange formed a pink colored radical cation with Se(IV) (selenite) in slightly acidic medium. The pink species had an absorption maximum at 568 nm with a molar absorption coefficient of 2.69×10^4 L/mol·cm and Sandell sensitivity of 2.94 ng/cm. Beer's law was followed over the concentration range of 0.10–5.50 mg Se/mL with a Ringbom optimum concentration range of 0.35–5.10 mg Se/mL. Maximum absorbance occurred when buffer solution of pH 6.59 was used. Samples were acid digested for the determination of total selenium and total tellurium. This method was simple, rapid, sensitive, reproducible and did not require extraction with organic solvent or heating. The authors determined trace amounts of Se in polluted water, plant material, and medicated shampoo.

2. Elleouet, C., F. Quentel, and C. Madec. 1996. Determination of inorganic and organic selenium species in natural waters by cathodic stripping voltammetry. Water Res. 30:090–914.

The authors proposed a selenium speciation model for the studies of natural waters based on Se(IV) voltammetric determination. The method included the separation of organic (i. e. selenoamino acids, dimethylselenides) and inorganic (i. e. SeO_3^{2-}, SeO_4^{2-}) forms of selenium species by a rapid ion exchange method. The Se (IV) concentration was directly determined by cathodic stripping voltammetry. Total selenium was determined after UV irradiation of the sample effected in alkaline medium under nitrogen. Se(−II) was determined by cathodic stripping voltammetry after percolating the sample on a resin IRA 400 followed by UV irradiation in acidic medium. Selenate concentration was calculated by subtracting selenite and selenomethionine concentrations from total selenium. The results obtained were reproducible, and in good agreement with other methods for selenium determination. Detection limits were low (about 5 ng/L) and the deposition time was about 10 min.

3. Filipovic-Kovacevic, Z. and I. Kruhak. 1996. Simultaneous determination of chromium, nickel and selenium by voltammetric techniques. Anal. Lett. 29(3):451–461.

The authors proposed a procedure for simultaneous determination of chromium, nickel, and selenium in their model mixtures, using adsorption stripping voltammetry (AdSV) for chromium and nickel and cathodic stripping voltammetry (CSV) for selenium. By a suitable choice of certain parameters, a simultaneous determination of these elements was achieved. The model mixtures contained Na_2CrO_4 for Cr, $NiClO_4$ for Ni and H_2SeO_3 for Se. The concentrations were successfully determined by simultaneous voltammetry. The lower detection limit was 5μM. Reliable results were obtained when the concentration levels of the metals were about the same. When the concentration of one of them exceeded that of the other two by 10-fold, the reduction processes for the three metals overlapped.

4. Gilon, N. and M. Potin-Gautier. 1996. Capillary electrophoresis applied to the determination of some seleno compounds. J. Chromatogr. A. 732(2):369–376.

Capillary electrophoresis, CE, provided a simple, yet reliable, analysis of selenite, selenate, selenocysteine and selenomethionine content in aqueous matrices. A small volume of a few nanoliters of sample rendered a highly efficient separation in a relatively short time. A chromate electrolytic buffer, containing trimethyltetradecylammonium hydroxide surfactant, was used to improve the UV detection sensitivity under optimum pH conditions.

5. Goosens, J., L. Moens, and R. Dams. 1994. A mathematical correction method for spectral interferences on selenium in inductively coupled plasma mass spectrometry. Talanta 41(2): 187–193.

The resolution of quadrupole mass analyzers was insufficient to resolve the parent ion, Se^+, from spectral interferences due to molecular species with the same nominal mass. This seriously hampered the determination of Se in biological samples. Some of these species are $ArCl^+$, $ArAr^+$ and SO_3^+. This method provides a mathematical solution to the problem based on the signal ratio measurement of $^{78}Se^+/^{76}Se^+$ and $^{78}Ar_2^+/^{76}Ar_2^+$. This method allowed for the correction of the argon dimer interference at m/z 78. The detection limit was 1μg/L. The method was applied to Se in human serum with good results.

6. Hao, D. Q., G. H. Xie, Y. M. Zhang, and G. J. Tian. 1996. Determination of serum selenium by hydride generation flame atomic absorption spectrometry. Talanta 43(4):595–600.

The authors used hydride generation flame atomic absorption spectroscopy, HGAAS, to determine total selenium in serum with accurate results. The samples were digested with a mixture of nitric and perchloric acids, treated with hot hydrochloric acid medium to reduce Se (VI) to Se (IV), and hydrogenated to H_2Se using sodium borohydride. The H_2Se sample was then transferred into a heated quartz tube under the flow of the argon carrier gas. The sample was atomized and the selenium determination was performed at a wavelength of 196.0 nm absorption. This method was then used to evaluate the selenium concentrations in the serum of 101 normal people and in 43 cancer patients. The range of selenium concentrations in the cancer patients was determined to be 38.7–88.3 μg/L, while non-cancerous patients had a higher concentration range of 81.6–140.4 μg/L . The relative standard deviations were 1.6–5.0%, with recovery rates of 97.3–99.2% when the selenium concentrations were in the 60.0–300.0 μg/L range. This method offered a detection limit of 1.55 μg/L, and simultaneously allowed for a simple, and accurate procedure for monitoring selenium concentrations.

7. Johansson, K., X. Luo, and A. Olin. 1995. Rapid one-step derivatization of Se(VI) to a piazselenol for the spectrofluorimetric determination of selenium in biological material. Talanta 42(12):1979–1987.

A new approach to the classic spectrofluorimetric determination of selenium was described. The method was used to determine total selenium concentrations in a wide variety of biological samples. The samples were subjected to strong oxidizing acids to destroy the organic material, and treated with hydrobromic acid to reduce Se(VI) to Se (IV). This Se species was treated with 2,3-diamino-1,4-dibromonaphthalene, Br_2-DAN, to produce 4,7-dibromo-5,6-

benzopiazselenol, Br_2-DAN-Se (selenous acid reacts with the monoprotonated *o*-diamine producing the piazselenol). This conversion was complete after only six minutes at temperatures of 100° C. The piazselenol was then extracted with cyclohexane and the fluorescence measured at 577 nm. This procedure allowed for the determination of total selenium in biological samples under simplified conditions.

8. Kubota, T., K. Suzuki, and T. Okutani. 1995. Determination of total selenium content in sediments and natural water by graphite furnace-atomic absorption spectroscopy after collection as a selenium(IV) complex on activated carbon. Talanta 42(7):949–955.

A trace level of Se was collected on activated carbon (AC) as the Se(IV)-3-phenyl-5-mercapto-1,3,4-thiadiazole-2(3H)-thione (Bismuthiol II) complex. The AC was directly introduced as an AC-suspension into the graphite tube atomizer and the total Se concentration was determined by atomic absorption spectroscopy. Heavily contaminated samples of sediment, lake water and seawater were digested and the total amount of Se was determined using this method.

9. Lan, W. G., and M. K. Wong. 1994. Microwave digestion of fish tissue for selenium determination by differential pulse polarography. Talanta 41:1:53–58.

A relatively simple, rapid and highly sensitive method for determining total Se in biological samples was developed. In a KIO_3-NH_3-NH_4Cl medium, the selenium complex $Se(O)SO_3^{2-}$, resulted from the reaction of selenite and sulfite in acid solution, gave a catalytic wave, which was detected using differential pulse polarography. The sample was decomposed using the $HNO_3/H_2SO_4/H_2O_2$ digestion mixture in a closed PTFE digestion vessel with microwave heating. The detection limit was 0.06μg/L.

10. Lan, W. G., M. K. Wong, and Y. M. Sin. 1994. Comparison of four microwave digestion methods for the determination of selenium in fish tissue by using hydride generation atomic absorption spectrophotometer. Talanta 41:2:195–200.

Four microwave digestion methods for selenium determination of fish tissue by hydride generation AAS were compared. Potassium hexacyanoferrate(III) was chosen as a masking agent for eliminating matrix interferences. The method comparisons showed that the use of HNO_3/H_2O_2, $HNO_3/K_2S_2O_8/H_2O_2$ and $HNO_3/H_3PO_4/H_20_2$ digestion media were unreliable. The calculated recoveries were in the 46–90% range, probably due to incomplete destruction of some of the organic selenium compounds. The decomposition using the digestion medium of $HNO_3/H_2SO_4/H_2O_2$ produced a good digestion of fish tissue and retention of selenium in a state amenable for determination. The recoveries of the spiked samples investigated ranged from 90 to 102%. The detection limit was 0.03 μg/g dry mass.

11. MacLeod, F., B. A. McGaw, and C. A. Shand. 1996. Stable isotope dilution-mass spectrometry for determining total selenium levels in plants, soils and sewage sludge. Talanta 43(7):1091–1098.

Isotope dilution-mass spectrometry, ID-MS, by gas chromatography-mass spectrometry, GC-MS, was used here to measure the selenium contents present in various types of samples. This technique offered the capability of simultaneously analyzing numerous elements, including selenium, in a wide range of matrices.

Chinese cabbage leaves and soil were the certified reference materials, CRMs, used to determine the degree of accuracy achieved using this technique. Additional samples included soils from the North East of Scotland, and sewage sludge samples from three locations in the UK. All samples were initially spiked with ^{76}Se isotope solution. The plant material was digested at 150°C using a mixture of hydrogen peroxide and nitric acid. Treatment with nitric acid, followed by digestion using hydrofluoric acid allowed for the release of selenium contained within the soil and sludge samples. The selenium was then reduced to Se(IV) and derivatized prior to analysis by gas chromatography-mass spectrometry using selected ion monitoring.

The selenium content of the soil CRM was determined to give a mean value of 1.67 ± 0.04 µg/g, whereas the cabbage leaves were analyzed to have 0.091 ± 0.007 µg/g. For both CRM measurements the results were within the 95% confidence intervals and the mean values, for nine analyses, were <10% higher than the certified concentrations. Additionally, the four Scottish soils were determined to contain between 0.5–1 µg/g selenium. The sewage sludges contained significantly higher selenium concentrations than the soils, with the selenium content ranging from 1.15 to 3.55 µg/g.

12. Manish, R., K. N. Ramachandran and V. K. Gupta. 1994. Extraction spectrophotometric determination of selenium(IV) with J acid in environmental samples. Talanta 41:1623–1626.

J acid [6-amino-1-naphthol-3-sulphonic acid (6-ANSA)] was used for the spectrophotometric determination of Se(IV). Se(IV) formed a yellow complex with J acid in the pH range of 1–2.5 (λ_{max} = 392 nm). The samples were digested to release the selenium prior to treatment with J acid. The complex formed was extracted in butanol, which increased the sensitivity about three times as compared to aqueous medium. The butanol extract had an orange-red color, and λ_{max} shifted to 520 nm with a molar absorption coefficient of 18.5×10^3 L mol^{-1} cm^{-1} and Sandell sensitivity of 4 ng cm^{-2}. Beer's law was followed over the concentration range of 0.03–0.3 mg Se/mL. The method was simple, rapid, sensitive, and reproducible. It was satisfactorily applied to the determination of trace amounts of total Se in polluted water, plant material, cereals, soil, human hair, and steel plant dust.

13. Narasaki, H. and J. Y. Cao. 1996. Determination of arsenic and selenium in river water by hydride generation ICP-AES. At. Spectrosc. 17:77–82.

The possibility of generating arsenic and selenium hydrides, thus separating these elements from a complex matrix, was the basis of this study. The sample was acid digested, total Se was determined as Se(IV) and total As was determined as As(V). The hydrides were generated in a mixing coil, and collected in a gas-liquid separator sealed with an electromagnetic pinch valve. They were codetermined with an inductively coupled plasma atomic emission spectrometer. The system was operated with variable-speed peristaltic pumps to separate the hydrides from the rest of the matrix. Interferences due to transition metals were eliminated by elution with Chelex 100 resin. The limits of detection obtained with this method are good (0.6 ng/ml for selenium), and the method was validated using biological standard reference materials. The values obtained were in good agreement with the certified values.

14. Örnemark, U. and Å. Olin. 1994. Preconcentration and separation of inorganic selenium on Dowex 1X8 prior to hydride generation-atomic absorption spectrometry. Talanta 41:1: 67–74.

This method details the exchange reactions between inorganic selenium species [Se(IV) and Se(VI)] and chloride on Dowex 1X8. The concentration exchange constants were determined with the batch technique at room temperature and used to predict the chromatographic enrichment and separation of tetra- and hexavalent selenium. Along with the procedure to separate and concentrate Se (IV) and Se (VI), a procedure for the determination of total inorganic selenium after digestion with permanganate and ion exchange preconcentration was developed.

15. Pathare, M. N. and A. D. Sawant. 1995. Extractive spectrophotometric determination of selenium(IV) using the sodium salt of hexamethyleneiminecarbodithioate. Anal. Lett. 28: 317–334.

The sodium salt of hexamethyleneiminecarbodithioate (NaHMICdt) was used for the spectrophotometric determination of Se(IV). The yellow complex was extracted in toluene using liquid-liquid extraction. Beer's law was followed over the concentration range of 0.5–4.0 mg Se/mL with a Ringbom optimum concentration range of 1.778–3.715 ppm Se. Extraction was maximum (99.75%) in 4 N HCl. Organic selenium was digested prior to analysis. The method was simple, rapid, sensitive, and reproducible and was satisfactorily applied to the determination of trace amounts of total Se in polluted water, plant material, wheat husk flour, and medicated shampoo.

16. Pickering, I. J., G. E. Brown, Jr., and T. K. Tokunaga. 1995. Quantitative speciation of selenium in soils using x-ray absorption spectroscopy. Environ. Sci. Technol. 29(2):2456–2458.

The authors analyzed aqueous selenite-selenate solution mixtures using hydride generation atomic absorption spectroscopy, HG-AAS, and synchrotron radiation-based X-ray absorption spectroscopy, XAS. The XAS method offered the ability to probe specific elements within a complex system. The major advantages of this method were the relatively small sample sizes, easy sample preparation requirements, lower costs, and the ability to perform consecutive measurements without destroying the prepared sample. In addition, analysis using the near-edge region of the XAS spectrum can be carried out *in situ* on undisturbed samples with detection limits as low as 10 ppm for soil samples. Data agreement with the HG-AAS results provided support that XAS is a viable instrument for selenium determination. Until now the XAS has not been utilized for the detection of trace elements. The samples analyzed were obtained from the Kesterson Reservoir. These included soil samples from an evaporation pond and one mushroom, *Agaricus bernardi.* The major phase of the Kesterson soil samples was determined to be monoclinic elemental selenium, while organoselenium species (>70% selenomethionine-like species) were determined to be predominant in the mushroom spectrum.

17. Ramachandran, K. N. and G. S. Kumar. 1996. Modified spectrophotometric method for the determination of selenium in environmental and mineral mixtures using 2,3-diaminonaphthalene. Talanta 43(10):1711–1714.

In the spectrophotometric method, 2,3-diaminonaphthalene is widely used owing to its lack of toxicity and ready availability. In this article, a modified spectrophotometric method for the determination of total selenium using 2,3-diaminonaphthalene was developed. In addition to 2,3-diaminonaphthalene, potassium bromide was also added as a catalyst. Se reacted with the reagent under acid conditions to form an extractable complex with an absorption maximum at 378.5 nm. The complex had molar absorptivity of 17.5×10^{3}/mol cm. The linear range of absorption was 0.5–12 mg/L. The limit of detection for selenium was 0.012 mg/L. The reproducibility was good. This method could be used in areas in which the traditional method can not be used, such as cattle feed and mineral mixtures.

18. Reddy, K. J., Z. Zhang, M. J. Blaylock, and G. F. Vance. 1995. Method for detecting selenium speciation in ground water. Environ. Sci. Tech. 29:1754–1759.

HGAAS method of Se analysis cannot separate Se into individual ionic species. Although the IC method can measure $SeO3^{2-}$ and $SeO4^{2-}$ simultaneously, $SO4^{2-}$ can interfere with $SeO3^{2-}$ and $SeO4^{2-}$ speciation. Ground water samples were analyzed for dissolved Se as ionic $SeO3^{2-}$ and $SeO4^{2-}$ by selectively adsorbing them onto copper oxide (CuO) particles after adjusting the pH to 5.5. These species were then desorbed from the surface of CuO particles by increasing the pH to 12.5. Subsequently, the concentrations of $SeO3^{2-}$ and $SeO4^{2-}$ ionic species in solution were determined with HGAAS and IC. The effect of cations such as Mg^{2+} was evaluated. This cation formed a neutral species with $SeO4^{2-}$ ($MgSeO_4$) which was not absorbed by the CuO particles, reducing the amount of $SeO4^{2-}$ extracted. The amount of selenium extracted with CuO was 97% for $SeO3^{2-}$ and 80% for $SeO4^{2-}$. This method is simple, effective, and can be used to sample ground waters in the field with an extraction as low as 7 (± 2) µg/L for both $SeO3^{2-}$ and $SeO4^{2-}$.

19. Safavi, A. and A. Afkhami. 1995. Catalytic spectrophotometric determination of selenium. Anal. Lett. 28:1095–1105.

This new method allows for the determination of Se(IV), Se(VI), and total Se. It is based on the catalytic effect of Se(IV) on the reaction of bromate with semicarbazide hydrochloride.

The products of the reaction react with resazurin and decolorize it. Resazurin shows absorption at 517 nm in acidic medium, and the reaction is monitored at this wavelength, concentration range of 50–4000 ng Se/mL. The limit of detection was 43 ng Se/mL. The method was satisfactorily applied to the determination of Se in Kjeldahl tablets and medicated shampoo.

20. Van Dael, P., R. Van Cauwenbergh, H. Robberecht, and H. Deelstra. 1995. Determination of Se in human serum by AAS using electrothermal atomization with longitudinal Zeeman-effect background correction flow injection hydride generation. At. Spectros. 16(6): 251–255.

Two methods are described for the determination of total selenium in human serum by atomic absorption spectrometry (AAS) using either electrothermal atomization (ET) with longitudinal Zeeman-effect background correction or flow injection (FI) hydride generation (HG). Accurate determinations of low selenium levels in small sample volumes (100 μL serum sample) were obtained with both methods after appropriate sample digestion.

21. Wang, D., G. Alfthan, and A. Aro. 1994. Determination of total selenium and dissolved selenium species in natural waters by fluorometry. Environ. Sci. Technol. 28(3):383–387.

A new fluorometry method was developed for the determination of total selenium and dissolved selenium species in natural waters. A resin column Dowex AG2-X8 was used for separation of selenite, selenate. Organic selenium was separated by XAD8 column. The elute was digested with HNO3 and reduced with HCl. 2,3-diaminonaphthalene was added to complex it. Cyclohexane was the extractant and the fluorescence was measured. The limit of the detection was 0.35 ng for total selenium and 1.8 ng for individual selenium species. The method was simple, sensitive, and accurate; samples were preconcentrated and acid digested.

22. Zhang, B., Y. Wang, X. Wang, X. Chen and J. Feng. 1995. Determination of antimony, arsenic, bismuth, selenium, tellurium and tin by low pressure atomic absorption spectrometry with a quartz tube furnace atomizer and hydride generation with air addition. Talanta 42(8):1095–1098.

To improve the sensitivity of the measurements and detection limits of selenium, antimony, arsenic, bismuth, tellurium and tin, the authors adopted a new method in the hydride generation-atomic absorption spectrometry process. They generated, collected and atomized the hydride at a pressure lower than atmospheric. The hydride generator generated and collected the hydride of these elements. A certain volume of air or oxygen was then added into the generator. The gaseous mixture of hydride and air was drawn into an evacuated, heated quartz tube by a vacuum pump. The influence of the hydrogen liberated from the decomposition was eliminated by the reaction of oxygen injected with the hydrogen liberated. Standard solutions were prepared and tested with this method. Results were satisfactory.

23. Zhu, B. and M. A. Tabatabai. 1995. An alkaline oxidation method for determining total arsenic and selenium in soils. Soil Sci. Soc. Am. J. 59:1564–1569.

A simple, accurate and precise method for determination of total As and total Se in soils was developed by the researchers. The method demonstrated the extraction of As and Se in a mixture of soil. The soil was combined with NaOBr and boiled to dryness in a sand bath,followed by acid digestion. The products, Se(VI) and As(V), were then reduced to Se(IV) and As(III). Total As and total Se were determined by an atomic absorption spectrometer with hydride generation. The range of concentrations that were analyzed in soils was 5.0 to 14.3 mg/kg for As and 0.5 to 5.5 mg/kg for Se. This method gives quantitative recovery (96–103%) of As and Se in certified standard reference materials and of these elements added to soils (99–101%). The digestion of soil samples with NaOBr and determination of the extracted As and Se by hydride generation AAS permitted rapid analysis of a large number of samples at a time.

TABLE 1. Summary of the bibliography.

	Method	Analytical Process	Limit of Detection	Environmental Applicability	Advantages	Disadvantages
1*	Xylenol orange	Spectrophotometric	—	Polluted water, plant material, medicated shampoo	Simple; does not require extraction	Te(IV) interferes
2	Ion exhange and sample fractionation	Cathodic Stripping Voltammetry	5 ng/L	Natural freshwater	Good sensitivity, speciation	Only for simple, clean matrixes
3	Adsorption	Cathodic Stripping Voltammetry (CSV)	1×10^{-8}M	Soil, water, mineral mixtures	Determination of Se without separating interfering ions	Not mentioned by authors
4	Trimethyltetradecy I-ammonium hydroxide surfactant	Capillary Electrophoresis	10 μg/L inorganic, species and 300 μg/L selenoamin o acids	Fresh waters	Small volumes, good reliability	Lack of selectivity and sensitivity
5	Quadrupole mass analyzer	Mathematical Correction	1 μg/L	Blood serum	Low detection levels	Some metals interfere (Ge, ^{39}K and $^{23}NA_2{}^{16}O_2$)
6	Acid digestion	Hydride Generation Atomic Absorption	1.55 μg/L	Blood serum	Sensitive, accurate, fast	Sample preparation, copper and arsenic interference
7	Wet/dry ashing, Br^2–DAN	Spectrofluorimetry	0.6 ng/g	Biological samples, food samples	Fast reduction rates, automated potentials	Laborious prep

TABLE 1. Continued.

	Method	Analytical Process	Limit of Detection	Environmental Applicability	Advantages	Disadvantages
8	Se(IV) complex	Graphite Furnace (GF)–Atomic Absorption Spectroscopy (AAS)	0.7 μg/g	Sediment, sea water, lake water, soil	Simple, rapid, applicable to heavily contaminated samples	AlF_3 needs to be removed
9	Se(IV) complex	Differential Pulsed Polarography	0.06 μg/L	Biological tissues	Simple, fast and highly sensitive method. Less expensive equipment is required.	Digestion procedure may not be complete. The sample matrix suppresses the Se signal.
10	Microwave Digestion	Hydride Generation–Atomic Absorption Spectrometry	0.03 μg/g dry mass	Biological tissue	Complete tissue digestion with the retention of Se. Interfering metals are masked using hexacyanoferrate(III).	The HNO_3/H_2SO_4/H_2O_2 digestion media may suppress the Se signal.
11	Acid digestion	Isotope Dilution–MS–GC–MS	Plants:0.09 μg/g Soils: 0.5 μg/g	Plants, soils and sewage sludge	Good precision and accuracy at low cost	Loss of precision and accuracy < 10 ng samples
12	J acid	Extraction Spectrophotometry	—	Polluted water, plants, cereals, soil, human hair, steel plant dust	Simplicity; Te (IV), V(V), and other metals don't interfere	Requires extraction in butanol

TABLE 1. Continued.

	Method	Analytical Process	Limit of Detection	Environmental Applicability	Advantages	Disadvantages
13	Hydride generation	Hydride Generation Inductively Coupled Plasma–Atomic Emission Spectrometry	0.6 ng/mL	Plant and animal tissues	Closed system, can be applied to many different samples	Multistep. Sensitive to interferences.
14	Preconcentration and Separation with Dowex 1×8	Hydride Generation–Atomic Absorption Spectrometry	25 ng/L	Natural waters	Decreased LOD, separation of Se (IV) and Se (VI) and removal of interferences	Need high purity resins, bicarbonate ion can cause interferences, sensitivity decreases with high salt content.
15	Hexamethylene–iminecarbodithioate	Extraction, Spectrophotometry	—	Polluted water, plant material, wheat husk flour, medicated shampoo	Simple; Te, Al, Mg, and some other ions do not interfere	Cd, Mn, and Zr interfere; requires extraction in toluene
16	Synchrotron radiation	X–ray Absorption Spectroscopy	10 ppm	Soils and plants	*In situ* analysis	Normalization, noise elimination
17	2, 3–diaminonaphthalene	Spectrophotometry	0.012 mg/L	Water, soil, cereal, mineral mixture and cattle feed	Good precision, rapid, simple, inexpensive	Low sensitivity

TABLE 1. Continued.

	Method	Analytical Process	Limit of Detection	Environmental Applicability	Advantages	Disadvantages
18	Selective absorption on CuO	HGAAS/IC	1 µ/L for HGAAS 1.81 µg/L for IC	Ground water	High sensitivity	Time-consuming
19	Resazurin	Catalytic Spectrophotometry	43 ng Se/mL	Kjeldahl tablets, medicated shampoo	Simple, selective, sensitive	V(III) interferes but can be extracted
20	Acid digestion	ET/AAS, FI/HGAAS	–ET/AAS: 6.5 µg/L	Human serum	–ET/AAS: Pd/Mg nitrate a better modifier.	–ET/AAS: subject to systematic errors
			–FI/HGAAS: 11.8 µg/L		–FI/HGAAS: Automated, reproducible. Allows interference–free determination	–FI/HGAAS: Not mentioned by authors
21	Se complex	Fluorometry	2.5 ng for total Se 1.8 ng for individual Se	Selenium in natural water	Sensitive, low-level detection	Not practical for field application
22	Hydride at subatmospheric pressure	HGAAS	60 pg	Trace amount of selenium and arsenic	Increased sensitivity. Elimination of H_2 interference.	Optimization of O_2 addition. Time consuming, error-producing.
23	Alkaline oxidation	HGAAS	0.5 mg/kg	Soils	Simple, accurate and precise method.	Possible interference from metals (Al, Cu, Fe, etc.)

* refers to number of bibliography.

LITERATURE CITED

Blair-West, J. R. and D. A. Denton. 1984. Selenium deficiency in cattle associated with heinz bodies and anemia. Science, 223:491–493.

Ge, K. and G. Yang. 1993. The epidemiology of selenium deficiency in the etiological study of endemic diseases in China. Am. J. Clin. Nutr. 57:259S-263S.

Gilliam, R. J. 1989. Preliminary assessment of sources, distribution and mobility of selenium in the San Joaquin Valley, California. Water Resources Investigations Report. U.S. Geological Survey, Sacramento, CA.

Gilon, N. and M. Potin-Gautier. 1996. Capillary electrophoresis applied to the determination of some seleno compounds. J. Chromatogr. A. 732(2):369–376.

Klayman, D. L. and W. H. H. Gunther. 1973. Organic Selenium Compounds: their Chemistry and Biology. John Wiley & Sons, Inc. New York, NY.

Lemley, R. E., and M. P. Merriman. 1941. Selenium poisoning in the human subject. Lancet 61:435–438.

MacLeod, F., B. A. McGaw, and C. A. Shand. 1996. Stable isotope dilution-mass spectrometry for determining total selenium levels in plants, soils and sewage sludge. Talanta 43(7): 1091–1098.

Rosenfeld, I., and O. Beath. 1964. Selenium. Geobotany, Biochemistry, Toxicity and Nutrition. Academic Press. New York, NY.

Salonen, J. 1982. Association between cardiovascular death and myocardial infarction and serum selenium in a matched pair longitudinal study. Lancet 2:175–179.

Spallholz, J. E., J. L. Martin, and H. E. Ganther. 1981. Selenium Biology and Medicine. The AVI Publishing Co., Inc. Westport, CT.

Steinhart, P. 1985. California's selenium dilemma. Audubon 87:111–114.

Virtamo, J., E. Valkeila, G. Alfthan, S. Punsar, J. K. Huttunen, and M. Karvonen. 1985. Serum selenium and the risk of coronary heart disease and stroke. Am. J. Epidem. 122: 276–282.

Wendel, A. (ed.) 1988. Selenium in Biology and Medicine. Springer-Verlag, Berlin.

Florida Scient. 61(1): 26–37. 1998
Accepted: July 18, 1997.

DESMOGNATHUS AURICULATUS AT DEVIL'S MILLHOPPER STATE GEOLOGICAL SITE, ALACHUA COUNTY, FLORIDA

C. Kenneth Dodd, Jr.

Florida Caribbean Science Center, Biological Resources Division,
U.S. Geological Survey, 7920 NW 71st Street,
Gainesville, FL 32653

Abstract: *The southern dusky salamander (*Desmognathus auriculatus*) was found commonly at the Devil's Millhopper, Alachua County, from the 1950s through the early 1970s. On 12 survey trips between April 1996 and March 1997, no salamanders were found despite intensive sampling. Although the habitat appears ideal for this species, it is now extirpated at this location. Although extensive land use changes have occurred around the site, the cause of the extirpation is unknown.*

The southern dusky salamander, *Desmognathus auriculatus,* is a semiaquatic plethodontid salamander occurring on the Atlantic and Gulf Coastal Plains from southeastern Virginia to eastern Texas. In Florida, it occurs throughout the northern half of the state; Ashton and Ashton (1988) report it as far south as Polk and Hillsborough Counties. Typical habitat includes cypress heads and swamps, sphagnum bogs, mucky areas bordering spring runs and streams, flatwoods ponds, and perhaps other boggy wetlands (Carr, 1940; Ashton and Ashton, 1988; Conant and Collins, 1991; O'Neill, 1995). Eggs are deposited in moist locations near water; the larvae are aquatic.

Very little is known concerning the life history of the southern dusky salamander in Florida. Most papers have examined the systematic validity of *D. auriculatus* (Rossman, 1959; Valentine, 1963; Christman, 1970; systematic history reviewed by Means, 1974), especially in view of Neill's (1951) description of *D. fuscus carri* from nearby Silver Glen Springs in Marion County. *Desmognathus f. carri* now is considered an ecophenotype of *D. auriculatus* (Means, 1974), and all peninsular desmognathines in Florida are allocated to *D. auriculatus.*

In the summer of 1970, Christman (1970) conducted a brief study of the desmognathine salamanders from Silver Glen Springs. He collected data on a variety of morphological characters, snout-vent-length and sex ratios, and provided histograms of population size-class structure (N=91 specimens). At this time, *D. auriculatus* were common in the seeps and surrounding wet woodland swamps.

In 1994 and 1995, Richard Franz (Florida Museum of Natural History) and I attempted to collect *D. auriculatus* at Silver Glen Springs on at least three collecting trips (June 1994 to March 1995). We searched the exact same areas studied by Christman, but we found no salamanders. Christman (1997) revisited the area and also was unable to collect any salamanders on several occasions, although he eventually found 2 or 3 individuals in November 1995; there did not appear to be any gross differences in the physical appearance of the habitat between the 1970s and mid-1990s.

The seeming rarity or disappearance of *D. auriculatus* at this and perhaps other sites in Florida and on the southeastern Coastal Plain (Harrison, 1992; Means, 1996) led me to investigate the status of the southern dusky salamander at the Devil's Millhopper State Geological Site, a site from which they had been reported to be common in the 1950s.

STUDY SITE—The Devil's Millhopper is located in the 28.57 ha Devil's Millhopper State Geological Site. The Site was acquired in two parcels (16.64 ha in 1974 from the University of Florida; 11.93 ha in 1977) to protect it from encroaching residential development. The Site is the only "State Geological Site" within Florida Park Service (FPS)-administered lands.

The Devil's Millhopper is a large sinkhole located at the northwest corner of the city limits of Gainesville, Alachua County, Florida (Lat. 29°42′29″, Long. 82°23′45″). The sinkhole measures approximately 152 m across at the top by 35.7 m deep; the walls are steep, but not sheer. It is formed in the Hawthorn limestone of middle Miocene age. Two separate collapses probably led to its present configuation, the last of which occurred about 1000 years BP. Water enters the sinkhole from approximately 12 springs which provide year-round flow. Numerous small seeps keep many of the steep sided walls wet.

The vegetation of the sinkhole and adjacent rim were described by Arnold (1936) based on surveys from 1929 to 1933. She divided the area into four zones (rim, upper walls, lower walls, and floor) and provided a checklist of plants from each zone. She and others noted the affinity of many plants with much more northern habitats. Through the years, however, vegetation changed dramatically with increasing human visitation and consequent erosion. A follow-up study 40 years later (Ford, 1978) found 29 plants absent from Arnold's (1936) checklist, and 23 plants present in 1976 but absent earlier. Most changes were associated with the loss of unique or unusual vascular plants and the invasion of "weedy" species. Today, much of the vegetation structure has recovered, although the plant composition remains rather different from the 1930s.

DESMOGNATHUS AURICULATUS AT DEVILS'S MILLHOPPER—*Desmognathus auriculatus* has been known from the Devil's Millhopper at least since the early 1950s. John Crenshaw, a student of Archie Carr of the University of Florida, conducted a limnological study of the springs and streams of the Devil's Millhopper (primarily on the eastern side) from late 1950 to early

1951. In a paper for Carr's class (Crenshaw, 1951), he mentions collecting 10 adults and 9 larvae. Adult salamanders were collected under leaf detritus, whereas larvae were collected in January 1951 from a quiet pool beneath a waterfall. They were also associated with debris.

From October 1951 to September 1952, Richard Highton, then a Master's student at the University of Florida, visited the Devil's Millhopper regularly in connection with his thesis project (a study of the salamander *Plethodon glutinosus* [=*grobmani*]). He found southern duskies to be "quite abundant" in the seeps and water courses on the sides of the sinkhole, and even considered doing a study of their life history (Highton, 1997). He noted that there was some temporal variation in abundance, but they were always present.

The only large collection of *D. auriculatus* from the Millhopper in the Florida Museum of Natural History (FLMNH) was deposited by Highton; his last specimens were collected in 1955. Additional specimens (N = 3) were deposited by Anne Meachem in March 1960, and a single specimen was deposited by L. D. Ober in March 1965. There are 177 specimens of *D. auriculatus* in the FLMNH from the Devil's Millhopper.

In April 1968, P. Moler conducted a study of the diet of *D. auriculatus* at the Millhopper in connection with a class at the University of Florida. He did not deposit specimens in the FLMNH. He recalls that the salamanders were quite common (Moler, 1997).

The Devil's Millhopper was the destination of many class field trips by students and faculty of the University of Florida. Franz (1997) recalls visiting the site with Carr's Community Ecology class in 1971 and finding *Desmognathus* to be common within the sinkhole. This appears to be the last verified record of *D. auriculatus* at the Devil's Millhopper. Christman (1997) also remembers visiting the site and seeing salamanders, although exact dates are unknown. By the time Marcus (1976) conducted a vertebrate survey throughout the park for a zoology class project, the salamander may have been already extirpated.

There has been some speculation that the *Desmognathus* of the Devil's Millhopper were different systematically from other local dusky salamanders. Stubbs (1972) noted that Millhopper duskies closely resembled *D. fuscus* in belly coloration and mottling and speculated on its cause. The idea that Millhopper *Desmognathus* might be related to *D. fuscus* apparently originated with Archie Carr, but there has been no formal examination of the salamander's systematics.

METHODS—Beginning in April 1996, I began a time-constraint sampling study in the lower ⅓ of the Devil's Millhopper (Arnold's [1936] zones 3 and 4) in areas where southern dusky salamanders previously had been collected. Each month, I and from one to six volunteers methodically searched streambeds, seeps, wet rock faces and waterfalls, and moist leaf litter in and adjacent to moist habitats on the floor of the sinkhole and along all lower walls. Wet rock faces and streambeds were searched using flashlights and leaf litter was turned and thoroughly searched using garden trowels. Search time generally was limited to one hour; because of the relatively small area to be searched, this allowed ample time to ascertain the presence of salamanders.

During searches, we determined whether prey species (spiders, earthworms, springtails, beetles or other small litter invertebrates) were active, and the presence of other herpetofauna. We noted water and air temperature (using an Atkins Series 396 Digital Thermometer), relative humidity (using a Nester Instruments RH Pen) and weather conditions. In March 1997, I recorded pH (using a LaMotte Model HA series pH meter) and conductivity (using a LaMotte Model DA series conductivity meter). Water quality and temperature data were recorded at a spring on the west side near the bottom of the sinkhole.

In the FLMNH, I measured standard length (tip of snout to posterior portion of the vent) of all *D. auriculatus* from the Devil's Millhopper. Dates of collection, collector, and larval characters were recorded.

RESULTS AND DISCUSSION—Twelve collecting trips were made at roughly monthly intervals from April 1996 to March 1997. A total of 57.5 person hours were spent searching for salamanders in the Millhopper ($\bar{x}$ = 4.8 hours/trip). No *D. auriculatus* were observed. Amphibians recorded included the green treefrog (*Hyla cinerea*), squirrel treefrog (*H. squirella*), spring peeper (*Pseudacris crucifer*), bronze frog (*Rana clamitans*), southern leopard frog (*R. utricularia*), southern toad (*Bufo terrestris*), and greenhouse frog (*Eleutherodactylus planirostris*); a single dwarf salamander (*Eurycea quadridigitata*) was observed in April 1996. The green treefrog, bronze frog, and southern leopard frogs can be considered common; bronze frogs, southern leopard frogs, spring peepers, and greenhouse frogs were heard calling from within the sinkhole.

The only reptiles observed within the sinkhole on our nocturnal surveys were cottonmouths (*Agkistrodon piscivorus*) seen in May, July, and December; size differences indicate that at least two individuals are present. I observed two turtles, presumably *Trachemys scripta,* basking on the side of the shallow pool in the bottom of the sinkhole during a diurnal photographic trip on February 17, 1997. A large eastern diamondback rattlesnake (*Crotalus adamanteus*) was captured on the eastern boundary of the State Geological Site on September 15, 1996.

Environmental conditions on all surveys seemed ideal for salamanders. Water always flowed down the sides of the sinkhole, numerous year-round seeps were present, invertebrates appeared abundant, and plenty of cover in the form of moist or wet leaf litter and surficial debris was present. Rock faces were always wet, and there were plenty of logs near seeps offering hiding places. Water temperature ranged between 15 and 25° C ($\bar{x}$ = 20.2), air temperature ranged between 13 and 28° C ($\bar{x}$ = 21.5), and relative humidity ranged between 57 and 88% ($\bar{x}$ = 74.5). Water pH was 7.4 and conductivity was < 0.05 micromhos in March 1997.

A total of 177 preserved specimens are in the collection of the FLMNH (3 have been cleared and stained but were not measured). Salamanders were collected in all months of the year except September (Table 1). Most salamanders were greater than 20 mm snout-vent length (SVL), and salamanders from 40 to 49.9 mm SVL comprised the two most numerous size classes

TABLE 1. Snout-vent length (mm) of *Desmognathus auriculatus* from the Devil's Millhopper preserved in the collection of the Florida Museum of Natural History.

Month	N	x̄	Minimum	Maximum	S.D.
Jan	7	38.7	15.2	49.1	11.7
Feb	17	37.1	16.5	58.1	12.0
Mar	7	44.1	35.7	51.3	6.5
Apr	9	30.1	17.2	49.8	13.6
May	17	37.7	21.2	48.3	9.3
June	27	36.5	18.9	56.5	9.7
Jul	6	39.0	23.7	47.7	8.2
Aug	48	37.6	13.4	54.7	10.2
Oct	15	27.6	9.2	49.8	17.6
Nov	11	33.2	11.9	55.0	15.9
Dec	10	40.9	11.7	56.9	12.8
Total	174	36.4	9.2	58.1	12.0

(Fig. 1). Animals < 22 mm SVL were distinctly larvae. One salamander 23.8 mm SVL retained larval features whereas one salamander 22.5 mm SVL did not have any presence of gill buds. Another salamander (24.4 mm SVL) appeared to be a very recent metamorph. Larvae were found in all months except March, July, and September. Very tiny hatchlings (9.2–10.1 mm SVL, N = 7) were found on October 7, 1955.

Life history—Based on the specimens in the FLMNH, it appears that *D. auriculatus* was active year-round in the Devil's Millhopper. Moderate water temperatures and an abundance of cover and invertebrate prey would seem ideal for activity throughout the year. Based on the size of the smallest larvae in each sample, eggs were probably deposited from August to December.

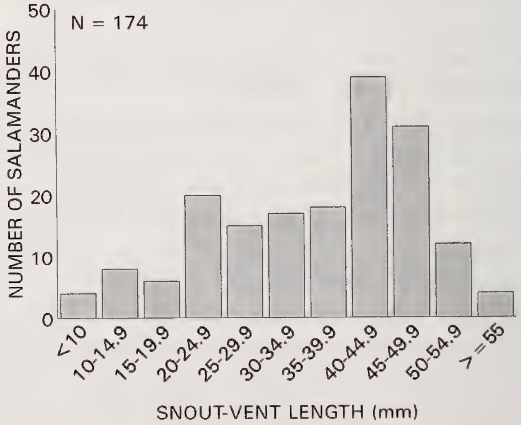


FIG. 1. Size-class structure of preserved *Desmognathus auriculatus* in the collection of the Florida Museum of Natural History from the Devil's Millhopper State Geological Site.

Neill (1951) noted a female guarding eggs in late October and another female with large oviducal eggs in January in Marion County to the south.

The smallest larvae in the FLMNH represent new hatchlings, so hatching occurred about 9 or 10 mm SVL. Larvae hatching one year probably transformed the following summer at from 22 to 24 mm SVL. Very large (old?) individuals may have been uncommon.

Status—By all accounts from herpetologists who had collected at Devil's Millhopper prior to the early 1970s, *Desmognathus auriculatus* was a common, if not abundant, salamander within the sinkhole. Evidence from the size-class structure suggests that the population was viable, and that reproduction was occurring. Unfortunately, this population now appears extirpated verifying Marcus's (1976) speculation based on a smaller sampling effort. The cause of extirpation, or causes, is not known.

Land use surrounding the Devil's Millhopper undoubtedly has changed many times since European colonization. The area seems to have contained a mosaic of habitats, from a typical sandhill community to more mesic flatwoods. Aerial photographs from 1937 show a sandhill community to the north, east, and southeast, cleared fields to the southwest, and what appears to be a hardwood hammock to the west. Many wetlands, sandhills, hammocks, flatwoods, and cleared agricultural fields were located more distantly.

Through the 1960s and into the early 1970s, the Millhopper was located in a rural setting. There were no houses or commercial developments anywhere near the sinkhole, although the area received considerable use from local residents and UF students as a place to visit and party, perhaps as early as the 1950s. Photographs in the collection of the FPS show extensive damage from erosion, and some portions of the sinkhole were nearly denuded of vegetation as a result of people sliding or climbing down its sides. Trails had been carved into the sides of the sinkhole as early as the 1930s during the era of the Civilian Conservation Corps, but they were not effective at preventing erosional damage. The acquisition of the property by the FPS in 1974 effectively closed the site to vandalism, and the vegetation structure now has recovered to pre-damage levels.

Beginning in the mid 1970s and continuing to the present, the flatwoods and hammocks surrounding the Millhopper have experienced substantial development. Initially, residential development centered on the western border of the Site, but both residential and commercial development now surrounds FPS land on three sides so that the sinkhole is a virtual island in a suburban neighborhood. Construction and land clearing resulted in substantial amounts of siltation running into the sinkhole, especially from a residential development to the west (data in files of FPS, District 2, Gainesville) via a small feeder stream, Deer Run. It is difficult to determine what effects occurred to the sinkhole's fauna as a result of the expanded development, especially in light of the severe erosion that resulted prior to 1974.

It seems clear from historical accounts by persons who collected the salamander at the Millhopper that it was very common at least through the early 1970s. Between then and the initiation of the present study, something happened to cause southern duskies to disappear. The cause of extirpation is unknown and, as such, is left to the realm of speculation. As with other amphibians (Dodd, 1997), duskies likely are subject to a wide variety of threats from adverse habitat modification or contamination. Inasmuch as the salamander spends much of its life in or near water, something affecting regional water quality in the early 1970s might have caused extirpation. Memos in the files of FPS (District 2, Gainesville) express concern over the water quality of the springs and occasionally have noted the presence of dead crayfish, but no water quality data are available.

The size of *Desmognathus* salamander populations may fluctuate widely over the course of years for reasons little understood (Means, 1996). However, it seems unlikely that any southern dusky salamanders remain at Devil's Millhopper. If they were extirpated by 1976 as suggested by Marcus (1976), then the sinkhole has not been recolonized.

ACKNOWLEDGMENTS—I thank Ray Ashton, Jaime Barichivich, Sam Cole, Patty Cramer, Elizabeth Domingue-O'Neill, Richard Franz, Ali Hamilton, Steve Johnson, Dale Johnson, Elizabeth Knizley, Dave O'Neill, Dave Prentiss, M. Randall, Lora Smith and Jennifer Staiger for assisting with the surveys. I especially thank my wife, Marian Griffey, who looked for salamanders during all surveys and graciously provided refreshments afterwards. Richard Highton, Dick Franz, Paul Moler, Steve Christman, and Bruce Means shared recollections of chasing salamanders at the Millhopper. I thank Sam Cole for his interest in the project, Junior Worrell for always keeping the gate open for us, and Dan Pearson for allowing access to FPS files. This survey was conducted under FPS Research/Collecting Permit No. 03129612.

LITERATURE CITED

ARNOLD, L. E. 1936. A field trip to the Devil's Millhopper. J. Elisha Mitchell Sci. Soc. 52:77–90.

ASHTON, R. E., JR. AND P. S. ASHTON. 1988. Handbook of the Reptiles and Amphibians of Florida. Part 3. The Amphibians. Windward Publ., Miami.

CARR, A. F., JR. 1940. A contribution to the herpetology of Florida. Univ. Florida Publ., Biol. Sci. Ser. 3:1–118.

CHRISTMAN, S. P. 1970. An examination of the desmognathine salamanders from Silver Glen Springs, Florida. Unpubl. rep., 23 pp. (copy in Herpetology Library, Florida Museum of Natural History, Gainesville)

———. 1997. Quincy, Florida, Pers. Commun.

CONANT, R. AND J. T. COLLINS. 1991. A Field Guide to Reptiles and Amphibians. Eastern and Central North America. Houghton Mifflin Co., Boston, MA.

CRENSHAW, J. 1951. A preliminary study of a rheocrene spring community in the Devil's Millhopper. Unpubl. rep., 23 pp. (files of FPS, District 2, Gainesville, FL).

DODD, C. K., JR. 1997. Imperiled amphibians: A historical perspective. *In*: G. W. Benz and D. E. Collins (eds.), Aquatic Fauna in Peril: The Southeastern Perspective. Spec. Publ. 1, Southern Aquatic Res. Inst., Lenz Design and Communications, Decatur, GA.

FORD, E. S. 1978. Vascular plants of the Devil's Millhopper during forty years of unrestricted use. Unpubl. rep. (files of FPS, District 2, Gainesville, FL).

FRANZ, R. 1997. Florida Museum of Natural History, Gainesville, Pers. Commun.

HARRISON, J. R. 1992. College of Charleston, Pers. Commun.

HIGHTON, R. 1997. Univ. Maryland, College Park, Pers. Commun.

Marcus, S. 1976. Vertebrate survey of the Devil's Millhopper State Geological Site. Unpubl. rep. (files of FPS, District 2, Gainesville, FL).

Means, D. B. 1974. The status of *Desmognathus brimleyorum* Stejneger and an analysis of the genus *Desmognathus* (Amphibia: Urodela) in Florida. Bull. Florida St. Mus., Biol. Sci. 18:1–100.

———. 1996. Coastal Plains Institute, Tallahassee, Pers. Commun.

Moler, P. 1997. Florida Game and Fresh Water Fish Commission, Gainesville, Pers. Commun.

Neill, W. T. 1951. A new subspecies of dusky salamander, genus *Desmognathus,* from south-central Florida. Publ. Res. Div. Ross Allen's Reptile Inst. 1(3):25–38.

O'Neill, E. D. 1995. Amphibian and reptile communities of temporary ponds in a managed pine flatwoods. M.S. thesis, Univ. Florida, Gainesville, FL.

Rossman, D. 1959. Ecosystematic relationships of the salamanders *Desmognathus fuscus auriculatus* Holbrook and *Desmognathus fuscus carri* Neill. Herpetologica 15:149–155.

Stubbs, T. 1972. Devil's Millhopper. Florida Wildl. 25(9):14–18.

Valentine, B. D. 1963. The salamander genus *Desmognathus* in Mississippi. Copeia 1963: 315–322.

Florida Scient. 61(1): 38–45. 1998
Accepted: July 23, 1997.

EFFECTS OF HUMIC ACID ON THE SOLUBILITY PRODUCT CONSTANTS OF SOME ENVIRONMENTALLY SIGNIFICANT CALCIUM COMPOUNDS

WARREN C. FISKUS AND THOMAS J. MANNING

Department of Chemistry, Valdosta State University,
Valdosta, GA 31698

ABSTRACT: *The effect that humic acid (HA) has on the solubility product constant (K_{sp}) of calcite ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2H_2O$) was determined. A flame atomic absorbance spectrometer was used to measure the aqueous phase calcium concentration in the solutions. The solubilities were measured as functions of humic acid concentration and pH. Calcite solubility was determined to be a function of $[H^+]$ and humic acid was determined to have a minimum effect on solubility. Gypsum solubility was unaffected by humic acid under normal environmental conditions but decreased at basic pH(9) and high humic acid concentration (10 ppm).*

HUMIC substances encompass an important group of organic compounds generated by decaying plant and animal matter. Humic substances are the end products of microbial degradation of organic matter (Christman and Gjessing, 1983)and account for 30 to 50% of the DOC (dissolved organic carbon) found in nature (Thurman and Malcolm, 1981). Aquatic humic substances originate in humic materials in soil and from decomposition of both terrestrial and aquatic plants (Thurman et al., 1982; Suffet and McCarthy, 1988; Gjessing, 1975). The morphology of aqueous humic acid colloids, which control much of the transport of hydrophobic pollutants and heavy metals in many natural aqueous systems, has been intensely researched (Homer, 1995). Humic substances are the most widely distributed natural products on the Earth's surface, occurring in soils, lakes, rivers, and oceans (Schnitzer and Khan, 1972). Humic substances are amorphous, brown or black colored, hydrophilic, acidic, polydisperse substances ranging in molecular weight from 500 to 500,000 amu.

Humic substances are divided into three main fractions: humic acid, fulvic acid, and humin. Humic acid is the fraction which is insoluble in water below a pH of 2. Humic acid is composed of a large, loosely defined group of aromatic and aliphatic structured organic compounds with high molecular weights up to 500,000 amu (Thurman et al., 1982). Humic acids are highly aromatic and have a carbon subclass called tannins which are esters of glucose or some other sugar with one or more trihydroxybenzoic acids and have the empirical formula $C_{14}H_{14}O_{11}$. Tannins have a yellow-white to brown color which deepens upon exposure to light and a faint, characteristic odor (Anon., 1993). Fulvic acid is the fraction of humic substances which is soluble under all pH conditions. The remaining fraction, humin, is insoluble in water at all values of pH and cannot be extracted by dilute base or acid. Humic substances play an important role in our environment because they can form stable water soluble and water insoluble salts, complex cations, anions and neutral species. Humic substances can act as buffers, solubilize insoluble organic compounds, generate trihalomethanes during chlorination of natural waters, and affect soil fertility. In the environment humic substances exhibit properties that effect trace metal chemistry, bioavailability and heterotrophic production in blackwater ecosystems (IHSS, 1995).

The original work in this laboratory centered on measuring the thermodynamic parameters (ΔG, ΔH, ΔS) of Ca^{2+}-HA interaction using an ion selective electrode (Gravely and Manning, 1995). These binding studies were then expanded to look at anion (F^-) binding to humic acid. Using these anion binding data, Hayes and co-workers (1995) postulated that humic acid binds by two methods: site binding and territorial binding. Site binding in humic acid typically involves a specific electrostatic interaction between one of the humic acid's functional groups (e.g., carboxylate, COO^-) and a cation (e.g., Ca^{2+}). Territorial binding involves the trapping of a cation, anion, or neutral species in the large structure, but not binding to a specific site. Anions prevalent in the environment (NO_3^-, Cl^-, etc.) can be trapped territorially. Past work has shown that fluoride (F^-) has pH dependent binding or trapping inside humic acid. Because F^- will not site bind any of humic acid's functional groups (e.g., carboxylate, phenolic, carbonyl, etc.), it was proposed that F^- was trapped inside the humic acid structure (Gravely and Manning, 1995). This work shows that anions can be "bound" or trapped in humic acid and that this binding is pH dependent. Specifically, carboxylates on humic acid become deprotonated as the basicity increases. This deprotonation leads to two effects, decreased hydrogen bonding causing the large humic acid structure to unravel, and carboxylates deprotonating and repelling the anions such as (F^-). As the $[H^+]$increases, the degree of H-bonding increases and protonation of carboxylate ions increases, thereby increasing the amount of trapping possible inside humic acid. Consequently, humic acid should territorially bind the components of gypsum (Ca^{2+}, SO_4^{2-}, $CaSO_4$) or calcite (Ca^{2+}, CO_3^{2-}, and $CaCO_3$) and might effect the solubilities of their minerals $CaCO_3$ and $CaSO_4$. This site binding of Ca^{2+} should decrease as the carboxylates protonate, but this effect is offset by the increased territorial binding.

Calcium sulfate dihydrate—This material ($CaSO_4.2H_2O$), also known as gypsum, is one of the more common minerals in sedimentary environments. Gypsum is normally white, colorless or gray, but can also be shades of red, brown, and yellow (Mottana et al. 1978). In the South Georgia and North Florida area, the middle Eocene Claiborne group overlies the Wilcox group, and is a dense, glauconitic, fossiliferous limestone containing interbedded dolomite and anhydrite ($CaSO_4$), gypsum ($CaSO_4.2H_2O$) and other evaporites. Gypsum is abundant, especially in the highly fossiliferous zones. Anhydrous calcium sulfate ($CaSO_4$) and gypsum in conjunction with other dissolved minerals are major causes of the high occurrence of low quality water for industrial applications in this area. In the lower zones, below a depth of 550 feet, the water has high content of minerals, trihalomethanes, and dissolved organic materials. The dissolved-solids concentration in this interval exceeds 2800 mg/L, and the sulfate concentration is around 2500 mg/L (Krause, 1979). The solubility of calcium sulfate has been extensively studied. Marshall and Slusher (1966) measured the K_{sp} of $CaSO_4 \cdot 2H_2O$ to be 4.231×10^{-7} in aqueous solutions of 6 molal NaCl and measured at temperature values over a temperature range of 0° C to 110° C. Marshall and coworkers (1964) measured the K_{sp} of $CaSO_4 \cdot 2H_2O$ to range from $4.22–3.57 \times 10^{-7}$ in varying molal concentrations (0 to 4 molal) of NaCl over a range of temperatures (40° C to 200° C). Yeatts and Marshall (1969) measured the K_{sp} of $CaSO_4$ to be 3.03×10^{-5} in aqueous solutions of $NaNO_3$ and Na_2SO_4 at varying ionic strength (0.25 to 6 molal) and at temperatures from 0° C to 350° C. Watters and Lambert(1969) measured the K_{sp} of $CaSO_4 \cdot 2H_2O$ to be 3.46×10^{-7} in 1 *M* tetramethylammonium chloride at 25° C.

Calcite—This form of $CaCO_3$ is a common mineral that is the main constituent of the sedimentary rock, limestone. Calcite comprises approximately 4% of the total mass of the Earth's crust, and it is found in almost all surface environments. Calcite has polymorphs known as aragonite and vaterite (Brecevic and Nielson, 1989, 1993). The color of calcite varies. Generally calcite is a light shade of white, yellow, orange, blue, pink, red, brown, green, black, or gray, and also exists in colorless forms (Mottana et al., 1978).

In the South Georgia and North Florida area, the aquifer runs through primarily Eocene and Miocene age limestone. The limestone in this area is a cream-to-white colored fossiliferous limestone containing abundant interbedded dolomite. The thickness of limestone less than 100 ft below the surface ranges from 20 to 60 feet. Calcium carbonate can be dissolved by circulating ground water, forming large underground cavities in the aquifer and eventually leading to aquifer collapse forming sinkholes (Krause, 1979). The solubility of calcite has been extensively studied. Wolf and co-workers (1989) measured the K_{sp} of calcite to be approximately 3.39×10^{-9} in different electrolyte systems at temperatures ranging from 10° C to 60° C and CO_2 partial pressures at 1kPa. Reardon and Langmuir (1974) measured the K_{sp} of calcite to be 3.98×10^{-9} in deionized H_2O varying the temperature from 10° C to 50° C using an ion selective electrode. Pytkowicz and Hawley (1974) measured the K_{sp} of calcite to be 5.67×10^{-7} using seawater at 25° C and an ion selective electrode. Garrels and Christ (1965) measured the solubility of calcite to be 8.34×10^{-7} at 25° C in deionized H_2O using an ion selective electrode. Oomori and co-workers (1988) measured the K_{sp} of cal-

TABLE 1. (Pk_{sp}) for $CaSO_4$ $2H_2O$ at varying concentrations of humic acid and varying pH.

pH	Blank (pK_{sp})	1 ppm (pK_{sp})	2 ppm (pK_{sp})	5 ppm (pK_{sp})	10 ppm (pK_{sp})
5	3.88 ± .006	3.85 ± .006	3.79 ± .005	4.00 ± .004	3.96 ± .008
6	3.92 ± .008	3.85 ± .006	3.85 ± .004	3.90 ± .005	4.06 ± .011
7	3.88 ± .004	3.84 ± .007	3.90 ± .004	3.96 ± .007	4.17 ± .011
8	3.90 ± .025	3.98 ± .007	3.84 ± .004	3.98 ± .009	4.85 ± .012
9	3.88 ± .005	3.88 ± .006	3.86 ± .004	4.18 ± .020	4.70 ± .029

cite to be 4.0×10^{-8} at 25° C using a saturometer in supratidal brine solutions. Brecevic and Nielson (1989) measured the solubility of amorphous calcium carbonate to be 4.0×10^{-7} at 25° C. Brecevic and Nielson (1993) measured the solubility of calcium carbonate hexahydrate ($CaCO_3.6H_2O$) to be 3.5×10^{-8} at 25° C.

MATERIALS AND METHODS--Stock solutions of humic acid were prepared by addition of technical grade humic acid from Aldrich chemical Co. (Cat. No. H1,675–2) to deionized H_2O. The solution was diluted into five stock solutions of concentrations at 1, 2, 5, and 10 ppm humic acid. The solutions were pH adjusted and allowed to stabilize for five days. The K_{sp} values were measured after the solutions were left to stand for five days. The pH range was 5 to 9, and the measurements were made at 25° C. Free calcium was measured using a Perkin-Elmer flame atomic absorbance spectrophotometer(model #2380) with an air-to-acetylene ratio of 3:1 at a wavelength of 422.8 nm, a slit width of 0.7 nm and a calcium hollow cathode lamp set at 8 milliamps.

RESULTS AND DISCUSSION—Table 1 shows the (pK_{sp}) measured in this experiment for gypsum at varying humic acid concentrations (0, 1, 2, 5, 10 ppm) and varying pH (5, 6, 7, 8, 9). A pH of 8 and an upper limit concentration of 1 ppm humic acid are similar to conditions found in some bays and harbors, whereas only part per billion concentrations are found in open seawater (Stumm and Morgan, 1981). A pH of 5 and a concentration of 10 ppm humic acid are similar to conditions and concentrations found in bogs or swamps. Over the range of normal environmental conditions mimicked here, the K_{sp} of gypsum is relatively stable. Only in basic solutions (pH 9) at a high concentration of humic acid around 10 ppm are changes in solubility observed. Under these conditions the K_{sp} of gypsum decreases, and other compounds (e.g., $Ca(OH)_2$, CaO, Ca-HA complexes, etc.) may form

TABLE 2. −log [Ca] for $CaCO_3$ at varying concentrations of humic acid and varying pH.

pH	Blank −log [Ca]	1 ppm −log [Ca]	2 ppm −log [Ca]	5 ppm −log [Ca]	10 ppm −log [Ca]
5	2.06 ± .005	1.51 ± .012	1.73 ± .008	1.34 ± .012	2.36 ± .007
6	2.24 ± .019	1.86 ± .009	2.43 ± .012	2.60 ± .034	3.35 ± .007
7	3.40 ± .005	3.43 ± .006	3.43 ± .009	3.71 ± .009	3.75 ± .007
8	3.79 ± .009	4.36 ± .022	4.30 ± .026	4.30 ± .020	4.26 ± .019
9	4.09 ± .038	4.73 ± .045	4.60 ± .045	4.51 ± .024	4.73 ± .051

thus invalidating K_{sp} measurements in this range. Table 2 gives the $-\log[Ca^{2+}]$data [pCa] that was measured for calcite. The trend we noticed for calcite is pH dependent and relatively unaffected by the concentration of humic acid in the solution. For this reason, the $[Ca^{2+}]$ was reported and not a K_{sp}. As the hydronium ion concentration $[H_3O^+]$ increased from 10^{-9} to 10^{-5} *M.* the solubility of calcite increased. This can be explained by the equilibrium (Eqn 1)

$$CaCO_3(s) + 2H^+(aq) \rightarrow H_2O(l) + CO_2(g) + Ca^{2+}(aq) \qquad (1)$$

The increase in acidity dissolves the carbonate resulting in an increase in $[Ca^{2+}]$. The concentration of humic acid does not show any consistent trend in affecting the K_{sp} of $CaCO_3$.

CONCLUSIONS—We conclude that the K_{sp} of calcite is affected primarily by the pH of the solution and not the humic acid concentration. From the gypsum solutions we concluded that humic acid has little effect on the solubility product under normal environmental conditions, but under basic conditions (pH 8 to 9) and high concentrations of humic acid (5 to 10 ppm) there is a decrease in solubility. We attribute this decrease to the formation of other minerals. The calcite solubility was not buffered to any appreciable extent by the humic acid concentration and the pH predictably played the greatest role in the carbonate solubility. In summary, past work in this laboratory showed that humic acid can bind both cations and anions. This observation led us to investigate humic acid's role in the solubility of some environmentally significant minerals. The effect of humic acid concentration on the K_{sp} of gypsum and calcite was minimal.

ACKNOWLEDGMENTS—We would like to thank German Mills at Auburn University for performing X-ray analysis on our samples. We gratefully acknowledge the Valdosta State University Chemistry Dept. for resources and laboratory space.

LITERATURE CITED

ANON. 1993. Microsoft Encarta. Microsoft Corporation. Seattle, WA.

BRECEVIC, L. AND A. NIELSON. 1989. Solubility of amorphous calcium carbonate. J. Crystal Growth 98:504–510.

——— AND A. NIELSON. 1993. Solubility of calcium carbonate hexahydrate. Acta Chem. Scand. 47:668–673.

CHRISTMAN, R. F. AND E. T. GJESSING. 1983. Aquatic and Terrestrial Humic Materials. Ann Arbor Science. Ann Arbor, MI

GARRELS, R. AND C. CHRIST. 1965. Solutions Minerals and Equilibria. Harper and Row, New York, 450 pp.

GJESSING, E. T. 1975. Physical Chemical Characteristics of Aquatic Humus. Ann Arbor Scientific. Ann Arbor, MI.

GRAVELY, E. D. AND T. MANNING. 1995. Determination of the thermodynamics of the calcium-humic acid complexation by an ion selective electrode. Florida Scient., 58:320–325.

HATCHER, P. G., M. SCHNITZER, L. W. DENNIS, AND G. E. MACIEL. 1981. Aromaticity of humic substances in soils. Soil Sci. Soc. Am. J. 45:1089–1094.

HAYES, D., J. CARTER, AND T. MANNING. 1995. Fluoride binding to humic acid. J. Radioanal. Nucl. Chem. 201 (2):135–141.

HOMER, V. 1995. Fractal dimension variability in aqueous humic acid colloids. http://aps.org/BAPSMAR95/abs/SJ2802.html.

IHSS Conference Paper. 1995. http://maurice.kent.edu/ihss2.html.

KRAUSE, R. E. 1979. Geohydrology of Brooks, Lowndes, and western Echols counties, Georgia. U.S. Geological Survey. Doraville, GA.

MARSHALL, W. L., R. SLUSHER, AND E. V. JONES. 1964. Solubility and thermodynamic relationship for calcium sulfate. J. Phys. Chem., 9(2):187.

——— AND R. SLUSHER. 1966. Thermodynamics of calcium sulfate dihydrate in aqueous sodium chloride 0° C to 110° C. J. Phys. Chem., 70(12):4015.

MOTTANA, A., R. CRESPI AND G. LIBORIO. 1978. Simon and Schuster's Guide to Rocks and Minerals. Simon and Schuster. New York, NY

OOMORI, T., K. KANESHIMA, AND Y. KITANO. 1988. Solubilities of calcite, aragonite, and protodolomite in supratidal brines of Minamidaito-Jima Island, Okinawa, Japan. Marine Chem. 25:57–74.

PYTHKOWICZ, R. M. AND J. E. HAWLEY. 1974. Bicarbonate and carbonate ion pairs and a model of seawater at 25° C. Limnol. Oceanogr. 19(2):223–234.

REARDON, E. J. AND D. LANGMUIR. 1974. Thermodynamics properties of the ion pairs $MgCO_3$ and $CaCO_3$ from 10° C to 50° C. Amer. J. Sci. 274:599–612.

SCHNITZER, M. AND S. U. KHAN. 1972. Humic Substances in the Environment. Marcel Dekker, New York, NY.

STUMM, W. AND J. J. MORGAN. 1981. Aquatic Chemistry (2nd ed.). John Wiley and Sons. New York, NY. pp. 375–376.

SUFFET, I. H. AND P. MACCARTHY. 1988. Aquatic Humic Substances. Adv. Chem. Ser. 219, American Chemical Society. Washington, D.C.

THURMAN, E. M. AND R. L. MALCOLM. 1981. Preparative isolation of aquatic humic substances. J. Am. Chem. Soc. 15(4):463–466.

———, R. L. WERSHAW, R. L. MALCOLM, AND D. J. PICKNEY. 1982. Molecular size of aquatic humic substances. Org. Geochem. 4:27–35.

WATTERS, J. I. AND S. M. LAMBERT. 1969. The complexes of calcium ion with pyrophosphate and triphosphate ions. J. Am. Chem. Soc. 81:3201–3202.

WOLF, M., O. BREITKOPF AND R. PUK. 1989. Solubility of calcite in different temperatures. Chem. Geol. 76:291–301.

YEATTS, L. B. AND W. L. MARSHALL. 1969. Apparent invariance of activity coefficients of calcium sulfate. J. Phys. Chem. 73(1):81–90.

Florida Scient. 61(1): 46–51. 1998
Accepted: August 15, 1997.

AN ANNOTATED BIBLIOGRAPHY OF ALLELOPATHIC PROPERTIES OF CATTAILS, *TYPHA SPP.*

MARIA T. GALLARDO, BARBARA B. MARTIN, AND DEAN F. MARTIN

Institute for Environmental Studies, Department of Chemistry,
University of South Florida, Tampa, FL 33620-5250

ABSTRACT: Typha, *a genus with widespread distribution in the United States, is a nuisance aquatic plant because of its ability to take over marshes and other freshwater environments usually to the extent of becoming monospecific. Many physiological characteristics contribute to this opportunistic invasion (size, growth habits, etc.) but release of allelopathic compounds into its surroundings seems to be an important mechanism in the encroaching of cattails at the expense of other plants. This annotated bibliography summarizes the chemistry of phytotoxins produced by cattails,* Typha spp. *and release of phytotoxins into the environment as the key to understanding its allelopathic behavior.*

CATTAILS, *Typha spp.* are probably the most familiar of all wetland plants. Their brown flower clusters can be seen at the edges of ponds, rivers, and lakes or just about any place where there is shallow, standing water for at least part of the year. Cattails are tall, erect plants that may grow to 6 to 8 feet tall. They usually grow along the shoreline but may also grow in water 3 to 4 feet deep. They are spread by creeping rootstalks and seeds. Different species of cattail occur commonly in wet soil, marshes, swamps and shallow fresh and brackish waters throughout the United States. Of the ten known cattail species, three can be found in Florida environments (Long and Lakela, 1976). Cattails have their function in the wetland ecosystem, providing places for nesting and protective cover for several animal species.

The plants and their flowers are edible during certain stages of growth. Aside from many food products and medicines, Native Americans used cattails for a variety of types of weaving. However, these days none of these uses is widespread and cattails are usually viewed as a nuisance aquatic plant (Smith, 1987). *Typha spp.* was the second most abundant aquatic species in Florida (after *Hydrilla verticillata* Royle), according to Schardt and Nall (1988).

The ability of cattails to expand over areas that were previously occupied by other species is well known and has been the subject of many studies over the years. In South Florida, *Typha domingensis* is believed to be a natural component of the Everglades ecosystem, occurring largely in scattered diffuse stands (Davis, 1994), but in many cases, it has become the dominant marsh species, out-competing native plants such as sawgrass, *Cladium jamaicense* (Toth, 1988). Its uncontrolled growth can lead to the formation of dense, monotypic stands and even to the clogging of waterways.

In the expansion of opportunistic *Typha,* many factors need to be considered, including its size, growth habits, adaptability to changes in the surroundings (nutrient levels, hydroperiod, shade) and the release of compounds that could prevent the growth of other species. This last feature can be considered as the essence of allelopathy, according to Rice (1984): "any indirect or direct harmful effect by one plant on another through production of chemical compounds that are released into the environment".

This annotated bibliography deals with the allelopathic properties of cattails, presenting information about the efforts that have been made in the characterization of the phytotoxins that *Typha* produces and releases into the environment. A better understanding of the chemical nature of these toxins could lead to the development of natural methods for the management of the uncontrolled expansion of *Typha.*

METHODS—The Aquatic Plant Information Retrieval System of the Center for Aquatic Plants (35,000 articles, reports and books) was searched, as was Scientific Technical Network (STN) International at the Institute for Environmental Studies. The list is not exhaustive, but every effort was made to include articles pertinent to Florida. Reports, theses, and dissertations were not included.

BIBLIOGRAPHY

ALBALAT DOMENÈCH, J., E. PÉREZ, M. T. GALLARDO, AND D. F. MARTIN. 1997. Identification of allelopathic chemicals in a pond of cattails. Florida Scient. 60: 202–203.

Sediment samples from a pond infested with *Typha domingensis* were screened for the presence of 2-chlorophenol and salicylaldehyde. These chemical compounds had been previously identified as major components in aqueous extracts of cattail plants and are thought to be among the species responsible for the allelopathic properties of the species. Using capillary gas chromatography, both compounds were detected in sediments close to the cattail growth front, but were not found in samples collected 2 m away from the plants.

ALLIOTTA, G., M. DELLA GRECA, P. MONACO, G. PINTO, A. POLLIO, AND L. PREVITERA. 1990. *In vitro* algal growth inhibition by phytotoxins of *Typha latifolia* L. J. Chem. Ecol. 16:2637–2646.

Ether extracts of *T. latifolia* were chromatographically separated and three steroids (β-sitosterol, (20S) 24-methylenlophenol and stigmast-4-ene-3,6-dione) as well as three fatty acids (α-linoleic, linoleic and an unidentified $C_{18:2}$) were isolated. Bioassays were conducted using crude *T. latifolia* extracts, as well as the purified compounds and the algicide $CuSO_4$ as control. Different algal strains were used as a subject. The crude extracts as well as the individual components were found to be able to inhibit the growth of some microalgae tested and a selective effect on blue-green algae (particularly on T 625 *Synechococcus leopoliensis* and on T 1444 *Anabaena flos-aquae*) was observed.

BONASERA, J., J. LYNCH, AND M. A. LECK. 1979. Comparison of the allelopathic potential of four marsh species. Bull. Torrey Bot. Club 106:217–222.

The allelopathic properties of four marsh species: *Ambrosia trifida, Peltandra virginica, Bidens laevis,* and *Typha latifolia* were evaluated using water leachates of different sections of the plant in a bioassay against lettuce, radish, tomato and cucumber seeds. Cattail extracts were found to be inhibitory to growth of all seeds and to radish germination in the first 24 h. Of the four plants evaluated, *Typha* extracts seemed to be the least inhibitory towards

growth and germination. Soil extracts of a cattail marsh were found to enhance cucumber growth at 72 h. and radish growth at 48 h.

Callaway, R. M. and L. King. 1996. Temperature-driven variation in substrate oxygenation and the balance of competition and facilitation. Ecology 77:1189–1195.

The ability of the aerenchymous wetland plant *T. latifolia* to aerate sediments and affect the growth of two non-aerenchymous neighbors, *Salix exigua* and *Miosotis laxa* was investigated. This was done in order to determine whether or not the cattails were able to facilitate the survival of the other two species by leaking oxygen into the rhizosphere. It was found that at low temperatures (about 11–12° C), a facilitation process was taking place and all the non-aerenchymous cuttings planted with the cattails survived while those planted alone did not; dissolved oxygen content in the cattail pots was higher than in the control pots. At higher temperatures (about 24–25° C), a competition process was observed, and the facilitation was no longer apparent. These results indicate that facilitation and competition may shift in importance with changes in the physical environment.

David, P. G. 1996. Changes in plant communities relative to hydrologic conditions in the Florida Everglades. Wetlands 16:15–23.

Variations in the distribution and percent cover of several plant species were examined with relation to hydroperiod in several locations in the Florida Everglades. It was found that, in contrast with other species, *T. domingensis* frequency and coverage showed no significant relationship with increased hydroperiod. It is suggested that some other environmental factor (such as input of phosphorus-enriched water) may play a role encouraging the encroachment of this species. It is also suggested that improved hydroperiod without water quality improvements may result in monotypic stands of *T. domingensis.*

Della Greca, M., P. Monaco, and L. Previtera. 1990. Stigmasterols from *Typha latifolia.* J. Nat. Prod. 53:1430–1435.

Several free and acylglucosilated stigmasterols were isolated from *T.latifolia.* Spectroscopic data as well as chemical modification studies were used in order to assign their structures. The oxidation pattern of the stigmasterols corresponds to that obtained by microbiological oxidation of cholesterol, and suggests the presence in *T. latifolia* of an enzymatic system able to transform β-sitosterol into the sterols reported here. However, the possibility that some of these compounds are being produced through an autooxidation process of b-sitosterol and stigmast-4-en-3-one cannot be ruled out.

———, L. Mangoni, and A. Molinaro. 1990. (20S)-4α- methylenecholest-7-en-3β-ol, an allelopathic sterol from *Typha latifolia.* Phytochemistry 29:1797–1798.

The structure of (20S)-4α-methylenecholest-7-en-3β-ol, a sterol isolated from ethereal extracts of *T. latifolia* was determined by means of spectroscopic studies and chemical correlation. This compound (2μmol) was tested in a paper disk bioassay against blue-green algae *Anabaena flos-aquae* and *Chlorella vulgaris.* The compound was found to be effective as a growth inhibitor for these two species.

Grace, J. B. 1983. Autotoxic inhibition of seed germination by *Typha latifolia*: an evaluation. Oecologia 59:366–369.

The effect of leaf extracts, leaf pieces, soil and soil water from *Typha latifolia* upon germination of its own seeds was studied. Leaf extracts were found to inhibit germination only in concentrations greater than 3% or equal; addition of soil to the culture increased the inhibition of seed germination. The inhibitory effects of extracts were correlated with the development of water molds in the cultures; prior to the development of water molds, even 15% extracts were not found to be inhibitory to germination. The results of this study are not conclusive about the allelopathic potential of *T. latifolia* towards the germination of its own seeds.

———. 1985. Juvenile vs. adult competitive abilities in plants: size dependence in cattails (*Typha*). Ecology 66:1630–1638.

T. latifolia and *T. domingensis* were tested to determine whether or not they exhibited size-dependent competitive abilities. Seeds of the two species were sown along a miniature gradient in water depth, both in monocultures and in mixtures. Over the entire gradient the two species did not differ significantly in their competitive properties. Adult plants were studied in a large artificial pond and it was found that *T. latifolia* was the dominant competitor over the entire gradient. It was concluded that the relative competitive abilities of *T. latifolia* and *T. domingensis* are size dependent; this could be associated with changes in morphology and physiology associated with growth and development, among other factors.

———. 1987. The impact of preemption on the zonation of two *Typha* species along lakeshores. Ecol. Monographs 57:283–303.
The rates of competitive displacement between two *Typha* species (*T. latifolia* and *T. domingensis*) growing along gradients of water depths were examined. It was found that seedling size, as well as initial density, have a strong influence in the early outcome of the competition. At high initial density, *T. domingensis* gained an early advantage; at lower densities, *T. latifolia* was a better competitor. Also, preemption had a strong effect on early growth and distribution of the species; in general *T. latifolia* recovered better than *T. domingensis* . Results suggest that if both species survive the initial competition phase and the habitat remains undisturbed, a predictable zonation will occur.

Mann, C. J. and R. G. Wetzel. 1996. Loading and utilization of dissolved organic carbon from emergent macrophytes. Aquat. Bot. 53:61–72.
Leachates from live and senescent tissues of *Juncus effusus* and *T. latifolia* was analyzed for dissolved organic carbon (DOC) and its availability to wetland bacteria. Photosynthetic leaves were found to have lower DOC levels and were able to support higher bacterial efficiencies than senescent tissue. For *T. latifolia* DOC concentrations were 1.4 (photosynthetic leaves) and 145.3 (senescent leaves) mg C L^{-1} cm^{-2} and supported bacterial efficiencies of 45% (photosynthetic leaves) and 4% (senescent leaves), respectively.

McNaughton, S. J. 1968. Autotoxic feedback in relation to germination and seedling growth in *Typha latifolia.* Ecology 49:367–369
Seed germination of *T. latifolia* in the presence of cattail leaf extracts was studied. Germination was completely inhibited in the presence of aqueous extracts of cattail leaves, but was only partially inhibited when phenolic compounds were removed from the water. Slight inhibition was observed with water from cattail marshes and high inhibition with water squeezed from soil in which cattails were growing. It is proposed that this may explain why cattail populations may preclude invasion from other species and also these autotoxic properties may be correlated with the unidirectional orientation of marsh succession.

Newman, S., J. B. Grace, and J. W. Koebel. 1996. Effects of nutrients and hydroperiod on *Typha, Cladium* and *Eleocharis.* Implications for Everglades restoration. Ecol. Appl. 6:774–783.
Experimental mixtures of *T. domingensis, Cladium jamaicense* and *Eleocharis interstincta* were subjected to two levels of nutrient concentration and three contrasting hydroperiods to determine how these variables might affect cattail's ability to displace the other two. The mixtures were set in outdoor tanks containing soil from the northern Everglades region. It was found that cattail development was enhanced by elevated nutrient concentration and increased flooding. The enhancement is associated with life story characteristics that include rapid growth rates, low tissue concentrations of phosphorus, tall leaves and a greater response to contrasting environmental conditions.

Ozawa, T. and H. Imagawa. 1988. Polyphenolic compounds from female flowers of *Typha latifolia* L. Agric. Biol. Chem., 52(2):595–597.
Female flowers of *T. latifolia* were extracted with acetone and subjected to a paper chromatography analysis. Eleven kinds of phenolic compounds were detected and their characterization was attempted. The compound present in the largest quantity was recovered and recrystallized and it was identified using IR and NMR data as *5-trans-* caffeoylshikimic acid

(also known as dactilifric acid). It was quantified using preparative HPLC and it was found to be present in a relatively high amount (6 mg per gram fresh weight). This compound was tested against a crude polyphenol oxidase prepared from the flowers, and was found to be responsible for flower browning. Other phenolic substances isolated and identified were epicatechin and afzelechin, but their relative amounts were very low, according to the qualitative paper chromatography data.

Pezeshki, S. R., R. D. Delaune, H. K. Kludze, and H. S. Choi. 1996. Photosynthetic and growth responses of cattail (*Typha domingensis*) and sawgrass (*Cladium jamaicense*) to soil redox conditions. Aquat. Bot. 54:25–35.

Photosynthetic activity and growth responses of cattail and sawgrass plants subjected to a range of soil redox potentials were measured. Cattail showed significantly greater net photosynthetic rates as compared with sawgrass at low Eh conditions. Also, under low Eh treatments, cattail total biomass reduction was greater than the corresponding sawgrass values. It is suggested that the differences between the two species in terms of site occupancy and competition may be partially explained by differences in their acclimatization to oxygen-deficient environments.

Prindle, V. and D. F. Martin. 1996. Allelopathic properties of cattails, *Typha domingensis,* in Hillsborough County, Florida. Florida Scient. 59:155–162.

Cattail plants (*T. domingensis*) in different stages of maturation were collected from two different locations near the University of South Florida campus in Tampa, FL. Aqueous extracts from different portions of the plants were found to inhibit the growth of lettuce and radish seeds; the same extracts were also able to inhibit oxygen production of *Lyngbya majuscula.* The observed allelopathic properties were conserved upon autoclaving. Partial purification using a C_8 column provided fractions containing inhibitory agents. These fractions were also tested in a bioassay using lettuce and radish seeds as the test organism in order to provide additional characterization of the allelopathic properties.

———, W. G. Sawyers, B. B. Martin, and D. F. Martin. 1996. Identification of allelopathic substances from cattails, *Typha domingensis.* Florida Scient. 60(SP 1):24–25.

Aqueous extracts of *T. domingensis* were fractionated and some fractions were found to exhibit allelopathic properties against lettuce seeds. Using gas chromatography/mass spectrometry, 2-chlorophenol and salicylaldehyde were identified as two major components in these extracts. These compounds are thought to be among the chemical species responsible for the allelopathic behavior of *T. domingensis.*

Seidel, K. 1975. Allelopathie und sukzession bei *Typha angustifolia* L. Naturwissenschaften 62:351.

General information concerning the allelopathic potential of *T. angustifolia* and its role in marsh succession is given. The species is well known for its ability to become monospecific when growing in water. When the growth front is in dry land, the plant enters the succession cycle, sharing space with other plants and, depending on the environmental conditions, ultimately becoming the dominant species. Some of the species that are outcompeted by cattail are: *Mentha aquatica* L., *Epilobium hirsutum* L., *Bidens tripartitus* L., and *Juncus effusus* L.

Stewart, H., S. L. Miao, M. Colbert, and C. E. Carraher. 1997. Seed germination of 2 cattail (*Typha*) species as a function of Everglades nutrient levels. Wetlands 17:116–122.

To assess the potential of cattails to replace sawgrass in Water Conservation Area 2A of the Florida Everglades, the germination of two *Typha* species (*T. domingensis* and *T. latifolia*) in response to different phosphate levels was studied. In experiments using field water it was found that the percentage of germination values are very similar for both species under low nutrient-level conditions (germination began after three days, reaching 22% to 40% in seven days). In the high nutrient- level range (up to 0.200 mg total phosphates / liter), *T. latifolia* germinated faster. Seed and fruit production traits were also evaluated. *T. latifolia* produced 1.4 times as many seeds as *T. domingensis,* but the mean seed weight of *T. domingensis* was

3.5 times that of *T. latifolia*. Results indicate that both cattail species are able to germinate under a variety of nutrient levels and pose a threat to sawgrass in the Everglades environment.

SZCZEPANSKA, W. 1971. Allelopathy among the aquatic plants. Polskie Archiwum Hydrobiol. 18:17–30.
Experiments were carried out to determine the interrelations between *Phragmites communis* and other aquatic species, including *Typha latifolia* in different environments. The decrease in reed production was usually accompanied by an increase in the cattail production. It was found that the type of soil modifies the growth of the cultures in monotypic stands, and it also influences the character of interrelations among the plants in mixed cultures. It was also found that the growth of reed could be inhibited by the introduction of dead cattail material in the growing medium.

——— AND SZCZEPANSKI, A. 1982. Interactions between *Phragmites australis* (Cav.) Trin. Ex Steud. and *Typha latifolia* L. Ekol. Pol. 30:165–186.
Experiments were carried out on a mixed culture of two helophite species: *Phragmites australis* and *Typha latifolia.* The interactions between these plants were determined on the basis of growth and production characteristics. It was observed that in mixed cultures, the cattail gained biomass while the reed lost it over time. The competition between the two species was interpreted as a consequence of the allelopathic behavior of the cattail plants.

———. 1987. Allelopathy in helophytes. Arch. Hydrobiol. Beih. 27:173–179.
A series of experiments were performed on allelopathic influences in helophytes, mainly between *Phragmites australis* and *Typha latifolia* and on the action of other helophytes on those species. It was found that *Typha latifolia* can inhibit the growth of the other species in most cases, and can even be inhibitory to *Typha angustifolia,* lowering its production by 64% (compared with *T. angustifolia* monocultures). *Eleocharis palustris* was found to inhibit *T. latifolia* development. The effects of allelopathy and those of environmental factors are very difficult to separate because of the variability of environmental factors during long term experiments.

SZCZEPANSKI, A. J. 1971. Allelopathy and other factors controlling the macrophytes production. Hidrobiologia 12:193–197.
The growth of certain reeds (*Phragmites* spp.) in the presence of other marsh species was investigated. It was found that the reed growth can be lowered by 61% in the presence of *Typha latifolia* under the experimental conditions. Decomposing plant debris was also found to be allelopathic. The intensity of the allelopathic effects is depends on the environmental conditions.

———. 1977. Allelopathy as a means of biological control of water weeds. Aquat. Bot. 3:193–197.
The allelopathic interactions between macrophytes in the Mazurian lakeland are briefly discussed. Under the climatic conditions of this particular environment, *Typha latifolia* is the most competitive species. However, if the stands are fertilized or grazed by cattle, the delicate environmental equilibrium can be shifted and other species may become dominant. With more research and the characterization of allelopathic compounds, weed control with allelopathic means could become a worthwhile approach that should be considered .

WANG, S. C., T. W. JURIK, AND A. G. VAN DER VALK. 1994. Effects of sediment load on various stages in the life and death of cattail (*Typha x glauca*). Wetlands 14:166–173.
Effects of burial by sediment on seed germination, seedling survival, growth of adults and litter decomposition of cattails were examined. It was found that seed germination was decreased by 60–90% when sediment loads of 0.2 to 0.4 cm were applied to the surface of the soil. The proportion of seedling survival increased with age and size of the seedlings. Sediment loads of up to 4 cm had no effect on adult plant density, number of leaves produced by plants or leaf photosynthetic characteristics or even on litter decomposition.

ACKNOWLEDGMENTS—We are grateful to assistance in obtaining copies of less-common journal articles from Ms. Karen Brown, Aquatic Plant Retrieval Information System, Center for Aquatic Plants, University of Florida. We thank Dr. Patricia M. Dooris for serving as Consulting Editor.

LITERATURE CITED

DAVIS, S. M. 1994. Phosphorus inputs and vegetation sensitivity in the Everglades. Pp. 357–378. *In:* Davis, S. M. and J. C. Odgen (eds.). Everglades: the Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, FL.

LONG, R. W. AND O. LAKELA. 1976. A Flora of Tropical Florida. Banyan Books, Miami, FL.

RICE, E. 1984. Allelopathy. 2nd ed. Academic Press, Inc. New York, NY.

SCHARDT, J. D. AND L. E. NALL. 1988. Florida Aquatic Plant Survey Tech Report #89-CGA. Bureau of Aquatic Plant Management. Florida Department of Natural Resources. Tallahassee, FL.

SMITH, S. G. 1987. *Typha*: Its taxonomy and the ecological significance of its hybrids. Arch. Hydrobiol. Beih. 27:129–138.

TOTH, L. A. 1988. Effects of hydrologic regimes on lifetime production and nutrient dynamics of cattail. Technical publication 88–6, South Florida Water Management District, West Palm Beach, FL.

Florida Scient. 61(1): 52–58. 1998
Accepted: August 6, 1997.

REVIEW

A. W. Smith, *A Gardener's Handbook of Plant Names—Their Meanings and Origins,* Dover Publications, Inc., Mineola, NY, 1997. Pp. xix + 407. Price: $9.95.

THIS republication of the 1963 classic will be a welcome addition to the bookshelves of gardeners, plant enthusiasts and botanists alike. For the amateur, there is a highly informative and entertaining introduction to the naming of plants, from the convention of the binomial system, to the rules of botanical Latin, and even a guide to pronunciation. The importance of scientific names in standardizing the identification of plants is brought out in a discussion of the varied and sometimes arbitrary use of common names in different parts of the world. This is important information for the commercial growers and promoters of cultivated plants who sometimes have no idea how to find the correct name for a plant and often make one up themselves. The bulk of the book is an alphabetical listing of commonly used names for both genera and species of plants. This includes conventional Latin names, latinized names from Greek and a variety of other languages, names derived from local place names, names derived from Greco-Roman mythology, and the names of the many botanists and other celebrities fortunate to have had plants named after them. There are many great stories that botany professors can use to liven up the classroom. For example, did you know that *Jubaea,* the genus of the Chilean Wine Palm is named after the King of Numidia who committed suicide when his ancient kingdom was absorbed into the Roman empire, or that *Juglans,* the walnut, means "acorn from Jupiter?" Prepare to be enlightened and entertained when you read this book.—Frederick B. Essig, Department of Biology, University of South Florida, Tampa, FL 33620.

BOOKS RECEIVED

CHILD, M.S. 1996 (1984). Molecular Collision Theory. Dover, Milola, NY. 310 pp. Paper, $9.95

DEYRUP, M. AND R. FRANZ (eds). R. E. ASHTON, JR. (ser. ed.). 1995. Rare and Endangered Biota of Florida. IV. Invertebrates. University Press of Florida, Gainesville. 828 pp. Cloth, $75.00; Paper, $39.95.

FERNALD, M. L. AND A. C. KINSEY. 1996 (1958 rev.). Edible Wild Plants of Eastern North America. Dover, Mineola, NY. 480 pp. Paper, $12.95

LEIGH, E. G., JR., A. S. RAND, AND D. M. WINDSOR. 1996. The Ecology of a Tropical Forest. 2nd ed. Smithsonian Institution Press, Washington, D.C. 501 pp. Paper, $29.95.

NATIONAL RESEARCH COUNCIL. 1997. Occupational Health and Safety in the Care and Use of Research Animals. National Academy Press, Washington, D.C. 154 pp. Paper, $39.95.

NELLIS, D. W. 1997. Poisonous Plants and Animals of Florida and the Caribbean. Pineapple Press, Sarasota, 315 pp.

RANDAZZO, A. E. AND D. S. DOUGLAS (eds). 1997. The Geology of Florida. University Press of Florida, Gainesville. 400 pp. $39.95.

RODGERS, J. A., JR., H. W. KALE, II, AND H. T. SMITH (eds). R. E. ASHTON, JR. (ser. ed.) 1997. Rare and Endangered Biota of Florida. V. Birds. University Presses of Florida, Gainesville. 736 pp. Cloth, $65.00; Paper, $29.95.

SMITH, A. W. 1997 (1963 rep.). A Gardener's Handbook of Plant Names, Their Meanings and Origins. Dover, Mineola, N.Y. 432 pp. Paper, $9.95.

PUBLISHERS' ADDRESSES

Dover Publications, Inc., 31 East 2nd Street, Mineola, NY 11501

National Academy Press, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. Tel: 202-334-3180

Pineapple Press, Inc., P. O. Box 3899, Sarasota, FL 34230. Tel: 800-PINEAPL

Smithsonian Institution Press, P. O. Box 960, Herndon, VA 22070-0960. Tel: 800-782-4612

University Press of Florida, 15 N.W. 15th Street, Gainesville, FL 32611-2079. Tel: 352-392-1351

INSTRUCTION TO AUTHORS

Individuals who wish to publish in the *Florida Scientist* must be active members in the Florida Academy of Sciences.

Submit a typewritten original and two copies of the text, illustrations, and tables to the editors. All typewritten material–including the abstract, literature citations, footnotes, tables, and figure legends–shall be double-spaced. Use one side of 8½ × 11 inch (21½ cm × 28 cm) good quality bond paper for the original; the copy may be xeroxed. Margins should be at least 3 cm all around. Number the pages through the Literature Cited section. Avoid footnotes and do not use mimeo, slick, erasable, or ruled paper. Use metric units for all measurements. *Papers in excess of 10 pages by an author in a single volume will result in page charges ($57 per page) for the excess pages.*

Address follows the author's name.

Abstract–all manuscripts shall have a short, concise, single-paragraphed abstract. The abstract follows immediately the author's address.

Acknowledgments are given in the body of the text preceding immediately the Literature Cited section.

Literature Cited section follows the text. Double-space every line and follow the format in the current issue.

Manuscripts of 5 or less, double-spaced typewritten pages should conform to the short article protocol. See recent issue for proper format of both long and short articles.

Tables shall be typed on separate sheets of paper, double-spaced throughout. Each table shall contain a short heading. Do not use vertical rulings. Maximum character width, including spaces, of tables is 98.0. This includes a minimum space of 5 characters between columns.

Illustrations–All drawings shall be done in good quality India ink, on good board or drafting paper. Letter by using a lettering guide or equivalent. Typewritten letters on illustrations are unacceptable. Drawings and photographs should be large enough to allow ⅓ to ½ reduction in size. Photographs shall be glossy prints of good contrast. Whenever possible, mount photographs in lots size.

The author's name and figure number should be penciled lightly on the back of each figure. Figure legends must be listed on a separate page and not on the drawing or photograph. The legend must be double spaced. Illustrations are charged to authors at $16.00 for halftones and $11.00 for line art.

We ask authors to prepare accepted manuscripts in personal computer formats. **Please do not submit a manuscript on disk.** Once reviewers have recommended a manuscript be accepted, you will be given directions for submitting the **final manuscript on disk.**

Proof must be returned promptly. Notification of address change and proofreading are the author's responsibility. Alterations after the type has been set will be charged to the author.

Reprints may be ordered through the Business Manager from the printer on forms provided at the time that proofs are sent to authors for checking.

FLORIDA ACADEMY OF SCIENCES

Institutional Members for 1998

Brevard Community College, Palm Bay
The British Library, Boston Spa, Weatherby, UK
The British Library, RAS Washington DC Professional Campus
Cleveland Public Library, Cleveland, OH
Edison Community College
Florida International University
Harbor Branch Oceanographic Institution, Inc.
Long Island University
Orlando Science Center
St. Petersburg (FL) Junior College
St. Thomas University
St. Thomas University Library
Saint Petersburg Public Library
Science Library, University of Chicago
University of Miami
University of North Carolina at Wilmington

Membership applications, subscriptions, renewals, and changes of address should be addressed to the Executive Secretary, Florida Academy of Sciences, Orlando Science Center, 777 Princeton St., Orlando, FL 32803.

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 University Blvd., Melbourne, FL 32901-6975 [(407) 768-8000, ext. 8196; e-mail rturner@fit.edu].

PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Prices quoted include domestic postage. Some issues may not be available. All are $20 per volume or $5 per issue, except for symposium issues.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES (1936–1944)
  Volumes 1–7
QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCE (1945–1972)
  Volumes 8–35
FLORIDA SCIENTIST (1973–)
Florida's Estuaries—Management or Mismanagement?—Academy Symposium
  FLORIDA SCIENTIST 37(4)–$5.00
Land Spreading of Secondary Effluent—Academy Symposium
  FLORIDA SCIENTIST 38(4)—$5.00
Solar Energy—Academy Symposium
  FLORIDA SCIENTIST 39(3)—$5.00 (includes do-it-yourself instructions)
Anthropology—Academy Symposium
  FLORIDA SCIENTIST 43(3)—$7.50
Shark Biology—Academy Symposium
  FLORIDA SCIENTIST 45(1)—$8.00
Future of the Indian River System—Academy Symposium
  FLORIDA SCIENTIST 46(3/4)—$15.00
Second Indian River Research Symposium—Academy Symposium
  FLORIDA SCIENTIST 53(3)—$15.00

Please send payment with order. If required, an invoice will be sent on purchases over $20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.

F63

ISSN: 0098-4590

Florida Scientist

FLORIDA ACADEMY OF SCIENCES 1936

Volume 61 Spring, 1998 Number 2

CONTENTS

Herpetofaunal Surveys of the Big Bend Wildlife Management Area, Taylor County, Florida .... Kevin M. Enge and Kristin N. Wood 61

Removal of Iron from Sodium Fluorosilicate Scale by Magnetic Treatment .... Chuhua Wang, Robert F. Benson, and Dean F. Martin 88

Florida and Global Warming .... Jay W. Palmer 96

Invasive Exotic Climbers in Florida: Biogeography, Ecology, and Problems .... Daniel F. Austin 106

Effects of Submergence on Embryonic Survival and Development Rate of the Florida Applesnail, *Pomacea paludosa:* Implications for Egg Predation and Marsh Management .... Richard L. Turner 118

Single Node Aquifer Analysis—A Water Budget Model .... R. P. Haviland 130

Book Review .... William H. Taft 139

Book Review .... Dean F. Martin 140

SMITHSONIAN
MAY 1 4 1998
LIBRARIES

FLORIDA SCIENTIST

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Copyright© by the Florida Academy of Sciences, Inc. 1998

Editor: Dr. Dean F. Martin Co-Editor: Mrs. Barbara B. Martin
Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, Florida 33620-5250
Phone: (813) 631-4121; e-mail: Martin@chuma.cas.usf.edu

Business Manager: Dr. Richard L. Turner
Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975
Phone: (407) 768-8000, ext. 8196; e-mail: rturner@fit.edu

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at $40.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

Officers for 1997–1998
FLORIDA ACADEMY OF SCIENCES
Founded 1936

President: Mr. Al Hall
City of Tallahassee
4335 Sherborne Road
Tallahassee, FL 32303

President-Elect: TBA

Secretary: Dr. Richard March
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416

Treasurer: Mrs. Georgina Wharton

Executive Secretary: Ms. Geralyn Heartz
Orlando Science Center
777 East Princeton St.
Orlando, FL 32803
407:896-7151, ext 2079; e-mail:
gheartz@osc.org

Program Chairs: Dr. George M. Dooris
and Dr. Patricia M. Dooris
Department of Science and Mathematics
St. Leo College
St. Leo, FL 33574

Published by The Florida Academy of Sciences, Inc.
Printing by Allen Press, Lawrence, Kansas

Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

DEAN F. MARTIN, *Editor* BARBARA B. MARTIN, *Co-Editor*

Volume 61 Spring, 1998 Number 2

Biological Sciences

HERPETOFAUNAL SURVEYS OF THE BIG BEND WILDLIFE MANAGEMENT AREA, TAYLOR COUNTY, FLORIDA

KEVIN M. ENGE(1) AND KRISTIN N. WOOD(2)

(1)Florida Game and Fresh Water Fish Commission, Joe Budd Wildlife Field Office,
Route 7, Box 3055, Quincy, FL 32351
(2)Florida Game and Fresh Water Fish Commission, Chinsegut Nature Center,
23212 Lake Lindsey Road, Brooksville, FL 34601

ABSTRACT: *Drift fence arrays were used to survey the herpetofauna of sandhill, sand pine (*Pinus clausa*) plantation, mesic flatwoods, coastal and inland hydric hammocks, basin swamp, dome swamp, basin marsh, depression marsh, and tidal marsh habitats in the Spring Creek (SC) and Tide Swamp (TS) units of the Big Bend Wildlife Management Area in Taylor County, Florida. We also surveyed xeric hammock in SC and scrub in TS. Sampling was conducted with 27 arrays in SC for 153 days in 1992 and with 20 arrays in TS for 218 days in 1993. We captured 1,916 amphibians of 25 species and 414 reptiles of 35 species in SC and 632 amphibians of 16 species and 350 reptiles of 29 species in TS. The proportion of aquatic, semiaquatic, terrestrial, arboreal, and fossorial species in comparable habitats in SC and TS typically differed because aquatic/semiaquatic species were proportionally more dominant in SC than in TS habitats. Capture rates were higher in SC than in TS because of more captures of aquatic/semiaquatic herpetofauna, especially in wetland habitats, which was probably related to greater precipitation and longer hydroperiods during the survey of SC. Weekly capture rates of amphibians were correlated with amount of precipitation in SC terrestrial and wetland habitats and in TS terrestrial habitats. Nine new species were documented for Taylor County. In wetland habitats sampled by silt-fence arrays, single arrays captured an average of only 54.3% (SC) and 68.1% (TS) of the total number of species documented in a given habitat type using multiple arrays. In terrestrial habitats sampled by metal-valley arrays, single arrays in SC and TS captured an average of 65.6% and 67.5%, respectively, of the total number of species documented in a habitat type using multiple arrays. During the first month of trapping, drift fence arrays captured an average of 59.4% (SC) and 31.1% (TS) of the total number of species that were eventually captured in a habitat type. Xeric hammock was the most productive terrestrial habitat and dome swamp the most productive wetland habitat in terms of herpetofaunal abundance and species richness. Herpetofaunal diversity of sand pine plantations was similar to that of altered sandhill habitat.*

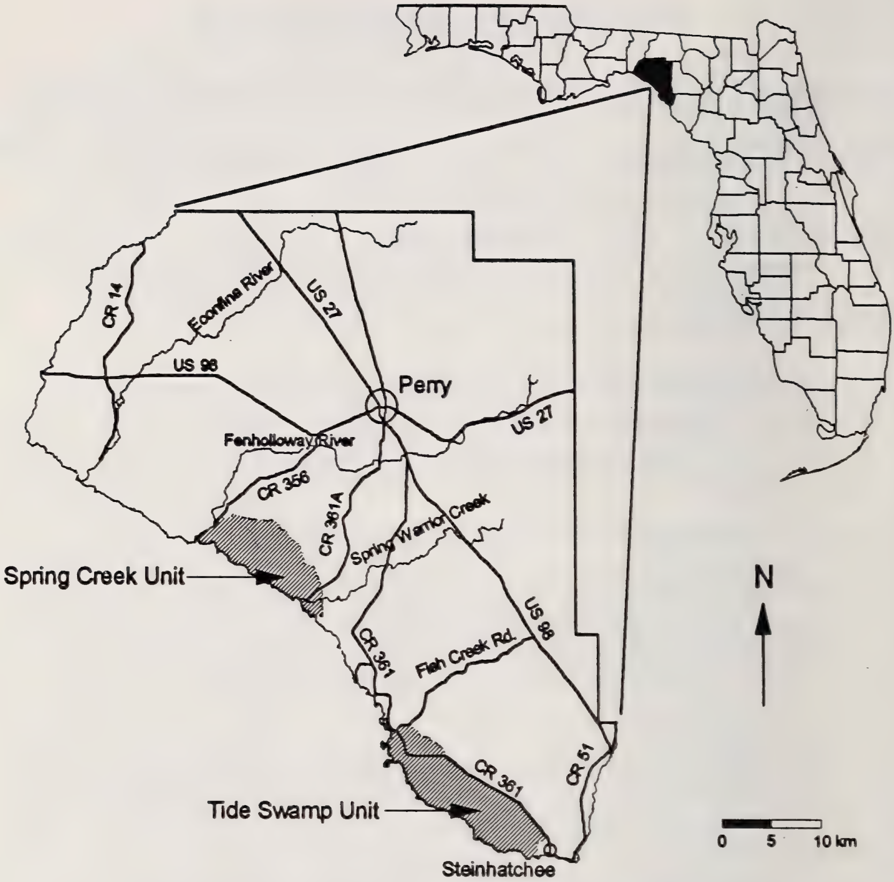


FIG. 1. Map showing the location of Spring Creek and Tide Swamp units of Big Bend Wildlife Management Area, Taylor County, FL.

DRIFT fences were used to conduct a herpetofaunal survey of terrestrial and wetland habitats in the Spring Creek (SC) and Tide Swamp (TS) units of the Big Bend Wildlife Management Area (WMA) bordering the Gulf of Mexico in Taylor County (Fig. 1). The low-lying Big Bend region is a transitional area between the upper Florida peninsula and the distinctive Florida panhandle (Neill, 1957). The distributional limits of at least 12 species of amphibians and reptiles and the intergradation zones of 11 subspecies occur in this region (Conant and Collins, 1991). Despite the herpetological significance of the Big Bend area, its herpetofauna has not been well studied. The only previous drift fence study conducted in the area was a short-term survey of various habitats in the Econfina River State Park, Taylor County (K. Studenroth, Florida Dept. Environ. Prot., unpubl. data).

A concerted effort to conduct drift fence surveys in under-sampled habitats in key areas of the state would provide current information on the distribution, habitat associations, relative abundance, and activity patterns of many herpetofaunal taxa. Drift fence surveys could provide important baseline data for future monitoring of herpetofaunal communities on public lands and allow the inclusion of biologically vulnerable taxa in management plans. Long-term surveys provide more complete lists of species and more meaningful relative abundance data than short-term surveys, which are more influenced by local weather conditions, species activity patterns, and annual differences in amphibian reproductive success. Impacts of certain land management practices on various taxa could be assessed by comparing relative numbers captured by drift fences in comparable areas subjected to different types or intensities of habitat alteration or other perturbations.

STUDY AREAS—*Location*—The SC study area encompasses ca. 5,190 ha along the Gulf of Mexico from 0.8 km east of the Fenholloway River to 3.5 km southeasterly of County Road 361A. The TS study area is comprised of ca. 8,213 ha along the coast from 2.9 km north of Hagen's Cove southeasterly to 1.3 km northwest of the town of Steinhatchee (Fig. 1). The coastal portions of the study areas were part of the Big Bend Aquatic Preserve Marsh Buffer.

Habitats—Many of the habitats in the Big Bend WMA had been previously altered by logging, mechanical site preparation, tree planting, drainage, and road construction. Large cypress (*Taxodium* spp.) and longleaf pines (*Pinus palustris*) had been logged and removed via tram roads, which still exist. By 1987, 53% of Florida's pine forests were in plantations (Bechtold et al., 1990), and all pineland sites surveyed in the Big Bend WMA had been clearcut and planted in sand, longleaf, or slash (*P. elliottii*) pine. Because monocultural pine plantations tend to have dense canopies, there is minimal sunlight penetration to the forest floor, resulting in a reduced ground cover and shrub layer. These conditions were most prevalent in sand pine plantations in our study areas. The hydrology of many wetland habitats was altered by elevated roads and roadside ditches.

Habitats were classified using the Florida Natural Areas Inventory's (FNAI's) system (Florida Natural Areas Inventory, 1990). In the following habitat descriptions, canopy layer refers to trees >5 m tall, shrub layer to woody vegetation 1–5 m high, and ground cover to grasses, sedges, forbs, and woody vegetation <1 m high.

No natural sandhill habitat remained in the two study areas, so we surveyed one site in an 11-year-old slash pine plantation in SC in which soils and remnant native vegetation indicated the former existence of sandhills. The shrub layer consisted of turkey oak (*Quercus laevis*), bluejack oak (*Q. incana*), and regenerating longleaf pines, and there was ca. 30% ground cover, primarily wiregrass (*Aristida beyrichiana*) (see Peet, 1993). We surveyed two former sandhill sites in TS planted to longleaf pine. These plantations had a subcanopy of turkey, live (*Q. virginiana*), and sand post (*Q. margaretta*) oaks; a shrub layer of scattered saw palmetto (*Serenoa repens*), sassafras (*Sassafras albidum*), cabbage palm (*Sabal palmetto*), and Chapman's oak (*Q. chapmanii*); and sparse ground cover consisting mostly of gopher apple (*Lichania michauxii*).

Sand pine was the predominant species planted on xeric sites in the WMA, and we surveyed three sand pine plantations in SC and two in TS. The SC sites were 11-year-old plantations with canopy closure ranging from 35–70%. The most densely planted site was formerly scrub habitat and had no shrub layer or ground cover, whereas the other two sites were formerly sandhill habitat and had a sparse shrub layer of sparkleberry (*Vaccinium arboreum*) and turkey, bluejack, and sand post oaks. The TS sites were 18-year-old plantations on former sandhill sites that had 50% canopy closure by sand pines and 5–10% shrub cover dominated by sand live oak, bluejack oak, turkey oak, yaupon (*Ilex vomitoria*), and saw palmetto. All the sand pine plantations had very little ground cover, and the soil surface was mostly covered with pine needles.

The two TS scrub sites had been planted 11 years ago with slash pines, which only had 5% canopy closure because of poor survival. Shrub cover was ca. 20% and consisted of saw palmetto, rosemary (*Ceratiola ericoides*), rusty lyonia (*Lyonia ferruginea*), and the classic scrub oaks—sand live (*Quercus geminata*), myrtle (*Q. myrtifolia*), and Chapman's oak. The three SC xeric hammock sites had ca. 50% canopy closure by mostly live oak and pignut hickory (*Carya glabra*). The shrub layer, which had 50% coverage, consisted of saw palmetto, Chapman's oak, laurel oak (*Q. hemisphaerica*), and sparkleberry.

The three SC mesic flatwoods sites had been bedded and planted 11–13 years ago with slash pines that now had ca. 20% canopy closure. Shrub cover was ca. 50% and consisted primarily of saw palmetto, gallberry (*Ilex glabra*), wax myrtle (*Myrica cerifera*), and fetterbush (*Lyonia lucida*). The two TS mesic flatwoods sites contained 28-year-old planted slash pines with 5–10% canopy closure. Shrub cover was ca. 50% on both sites; the better-drained site had rusty lyonia, cabbage palm, and live oak, and the other site had saw palmetto, gallberry, wax myrtle, poison sumac (*Rhus vernix*), and rusty lyonia.

Three sites in SC were situated near the coast in hydric hammocks containing cabbage palm, southern red cedar (*Juniperus silicicola*), diamond-leaf oak (*Quercus laurifolia*), water oak (*Q. nigra*), red maple (*Acer rubrum*), and swamp bay (*Persea palustris*) with 35–50% canopy closure. All sites had 30–50% shrub cover—needle palm (*Rhapidophyllum hystrix*), saw palmetto, wax myrtle, dahoon (*Ilex cassine*), and yaupon—and 20–40% ground cover of sawgrass (*Cladium jamaicense*) and sedges (*Carex* spp.). The two TS coastal hydric hammocks differed greatly from each other. One site consisted of a stand of southern red cedars and cabbage palms with a ground cover of sawgrass in an expanse of black needlerush (*Juncus roemarianus*). The other site had a canopy of red maple, cabbage palm, southern red cedar, swamp bay, green ash (*Fraxinus pennsylvanicus*), and Florida elm (*Ulmus floridana*), and a shrub cover of cabbage palm, bluestem palmetto (*Sabal minor*), yaupon, and wax myrtle.

Three sites in SC and two sites in TS were situated in more inland hydric hammocks, three of which had standing water only after heavy rains and two usually had standing water in shallow depressions. The SC sites had ca. 70% canopy cover of predominantly cabbage palm, red maple, diamond-leaf oak, pond cypress (*Taxodium ascendens*), green ash, loblolly pine (*Pinus taeda*), Florida elm, and swamp bay. Shrub cover was 10–25%, mostly bluestem palmetto and yaupon, and ground cover was sparse sedges. The TS sites had 60–70% canopy cover of southern magnolia (*Magnolia grandiflora*), cabbage palm, pignut hickory, sweetgum (*Liquidambar styraciflua*), diamond-leaf oak, sweetbay (*M. virginiana*), and red maple. Shrub cover was 20–30%, primarily bluestem palmetto, needle palm, American hornbeam (*Carpinus caroliniana*), wax myrtle, and small canopy species. Ground cover was dominated by sedges and southern shield fern (*Dryopoteris ludoviciana*).

We surveyed three small dome swamps in mesic flatwoods in SC and two dome swamps in wet flatwoods in TS. The SC dome swamps had ca. 50% canopy closure by pond cypress and lesser amounts of blackgum (*Nyssa biflora*), slash pine, and various bays (*Persea* spp.) Shrub cover ranged from 30–60% and was dominated by wax myrtle, fetterbush, and dahoon holly. Swamp interiors had 10–30% ground cover of sawgrass and scattered royal ferns (*Osmunda regalis*), but the periphery had greater sawgrass density. The TS dome swamps had 50–65% canopy closure by pond cypress, cabbage palm, swamp bay, diamond-leaf oak, and slash pine. Shrub cover was only 5%, and ground cover was mostly absent in swamp interiors, although sawgrass was dense around the periphery.

One of the three basin swamp sites in SC had ca. 50% canopy cover of cabbage palm, green ash, diamond-leaf oak, red maple, blackgum, and sweetbay. Shrub cover was ca. 20%, and ground cover was ca. 60%, primarily grasses and ferns. The other two sites had longer hydroperiods, greater canopy closure (70–80%), and less ground cover (<10%). The shrub layer (5–40% cover) of fetterbush, wax myrtle, and small canopy tree species was primarily restricted to hummocks associated with buttressed tree trunks or upraised roots. The canopy was dominated by pond cypress, red maple, sweetgum, blackgum, diamond-leaf oak, green ash, sweetbay, and swamp bay. The two TS basin swamp sites had 60–70% canopy cover of diamond-leaf oak, swamp bay, blackgum, green ash, red maple, sweetbay, cabbage palm, and sweetgum. One of the sites usually had standing water, and shrub cover was 15%. The other site typically had standing water only in low spots, and shrub cover was 50%. Shrub cover was dominated by fetterbush and swamp bay, and sedges and ferns composed the 30–40% ground cover.

The low-energy karstic coastline of the Big Bend area has an intricate mosaic of marshes and coastal hammocks. The vegetation zonation and salinities of the marshes are controlled by small changes in elevation, tidal inundation, edaphic conditions, and freshwater flow. The depression and basin marshes surveyed near the coast were potentially influenced by tidal surges, and may periodically have contained brackish water. The extensive tidal marshes of the Big Bend Region are irregularly flooded by a combination of lunar and wind-blown tides and a seasonal rise in sea level (Montague and Wiegert, 1990).

Two small depression marshes were surveyed in SC. One marsh was located in a mesic slash pine plantation and had a border of blackgum, wax myrtle, sweetbay, and fetterbush. The interior had 70% coverage by horsetails (*Equisetum* sp.), whereas soft rush (*Juncus effusus*) dominated the periphery. The other marsh was located in a densely planted slash pine plantation in either former wet flatwoods or hydric hammock. The marsh was densely vegetated by black needlerush (indicative of at least slightly brackish water) and bordered by wax myrtle, slash pine, cabbage palm, red maple, blackgum, and dahoon holly. The only TS depression marsh surveyed was situated in flatwoods and had 75% coverage by sand cordgrass (*Spartina bakeri*) and a border of scattered slash pine, blackgum, saw palmetto, wax myrtle, and gallberry.

The large SC basin marsh was contiguous with coastal marshes but contained fresh water. The periphery contained cabbage palm, slash pine, and live oak, whereas the interior was primarily sawgrass. The TS basin marsh was situated in flatwoods and bordered by dense gallberry under a canopy of slash pines. The interior had 40% coverage by black needlerush, whereas sand cordgrass dominated the perimeter. Both these marshes were probably subject to saltwater influx during tidal surges associated with tropical storms.

Two survey sites in SC were along the coast in brackish marshes inland of the tidal marsh, which was inaccessible to convenient sampling. The site nearest the Gulf of Mexico was completely vegetated with black needlerush, whereas the more inland site had a mosaic of black needlerush, sawgrass, and saltgrass (*Distichlis spicata*). The two TS tidal marsh sites were ca. 70 m from each other in <1-m-high black needlerush with ≤50% coverage.

METHODS—Surveys were conducted using drift fences in conjunction with funnel and/or pitfall traps in a modified three-fence array design described by Jones (1986). The three arms of the array were 7.6-m long and met at a centerpoint at 120° angles.

In scrub, sandhill, sand pine plantation, xeric hammock, mesic flatwoods, and inland hydric hammock habitats, we used 50-cm wide galvanized valley, or flashing, for the drift fence material. A 19-liter (5-gallon) plastic bucket with drainage holes in the sides ca. 2 cm from the bottom was sunk into the ground at the centerpoint of the array. A single-opening funnel trap (86 cm long, 25 cm diameter) was placed at the distal end of each fence, and a double-opening funnel trap (86 cm long, 20 cm diameter) was situated at the midpoint of the fence on each side. Funnel traps were constructed of aluminum window screen fastened together with office staples.

In coastal hydric hammock, dome swamp, basin swamp, depression marsh, basin marsh, and tidal marsh habitats, pitfall traps were eliminated and silt fencing material was used for the fences. Silt fencing is a black, woven, polypropylene material that is 92-cm wide and comes already attached to wooden stakes (Enge, 1997). Each TS array had a single-opening funnel trap at the distal end of the fence on each side, but double-opening funnel traps were used instead in SC. A double-opening funnel trap was also placed on each side of the fence ca. 2.5 m from the center stake. Thus, a silt-fence array had 12 funnel traps, whereas a metal-valley array had one pitfall and nine funnel traps.

We used silt fencing because it effectively captures the same species as metal-valley but is significantly less expensive and easier to install, especially in wetland habitats. Silt fencing provides a higher barrier than metal valley, but stakes on one side of the silt fence may facilitate some animals (e.g., snakes) ascending the fence. Although the fabric of silt fencing may make it easier for lizards to climb the fence, arboreal lizards are frequently captured in funnel traps along silt fences (Enge, 1997).

Both pitfall and funnel traps were shaded with 41-cm square masonite boards and provided with a moistened sponge to keep small animals from desiccating. Shade covers were propped at ca. 45° angles over double-opening funnel traps and laid on top of the closed end of single-opening funnel traps. The center pitfall trap of the metal-valley arrays was shaded by balancing the masonite board on top of the juncture of the three fences.

Trapped animals typically were released ca. 3 m away on the opposite side of the fence. Manpower constraints precluded marking trapped individuals, so total number of captures, including original and recaptures, was used in the analyses. Newly metamorphosed anurans are included in the capture totals, but larval amphibians are not because of difficulties involved in species identification.

Three drift fence arrays were placed in each habitat type sampled in SC, except for sandhill (one array) and tidal marsh (two arrays) habitats, for a total of 27 arrays. Two arrays were placed in each TS habitat type sampled for a total of 20 arrays. The freshwater-marsh arrays consisted of two arrays in depression marshes and one array in a basin marsh in SC and one array in each marsh type in TS. We installed drift fence arrays >100 m apart within a habitat type and tried to select different microhabitats to maximize the number of species obtained. Some arrays in xeric habitats were situated in the vicinity of wetlands. The SC sandhill array was 40 m from a depression marsh. Two of the SC xeric hammock arrays were in an area with scattered small sinkholes that were seasonally wet, whereas the third array was situated ca. 150 m from a permanent stream.

Trapping was conducted for 153 days (29 May 1992–29 October 1992) in most habitats in SC and for 218 days (25 March 1993–29 October 1993) in TS. However, trapping was terminated after only 85 days in SC tidal marshes because of excessive disturbance and frequent destruction of traps by raccoons (*Procyon lotor*). The trapping period was only 214 days in TS sand pine plantations because of impending logging. A total of 3,995 and 4,352 array-days of sampling was conducted in SC and TS, respectively. We calculated capture rates as the number of individuals captured array^{-1} day^{-1} (i.e., array-day; Campbell and Christman, 1982a; Corn, 1994) × 100. This standardized measure permitted comparisons of capture rates between the two study areas despite differences in numbers of arrays used and trapping duration.

Traps were checked an average of every four days in SC and every five days in TS. Traps were generally checked more frequently (at two- to three-day intervals) during periods of high precipitation, when large numbers of amphibian captures were anticipated. Temperature and rainfall data were collected at two sites in each study area using a maximum-minimum thermometer and rain gauge. Precipitation often varied between the two sites, so we averaged the precipitation data from each collection period. Water depths at the center of wetland arrays were recorded sporadically.

RESULTS—*Species richness of habitats and study areas*—We used species richness (the number of species) instead of diversity indices because measures that include abundance are confounded by differences in capture rates among species and numerical dominance by a few species. Twenty-five amphibian and 35 reptile species were captured in SC and 16 amphibian and 29 reptile species in TS (Table 1), despite 357 more array-days of sampling effort in TS.

Drift fences in TS captured only 54.5–78.3% of the species captured in SC in the six habitats that were comparable in both study areas. Twelve of the 15 species not captured in TS were aquatic or hylid (*Hyla, Pseudacris*) species. Although the bronze frog, gulf salt marsh snake, corn snake, and Florida pine snake (see Table 1 for scientific names) were only captured in TS, the latter two species were observed crossing roads in SC, and the other two species undoubtedly also occur there.

The species richness of comparable habitat types was lower in TS than in SC (Table 1). Overall species richness in the four SC habitats sampled using metal-valley arrays ranged from 23 species in coastal hydric hammock and sand pine plantation to 29 species in xeric hammock. In SC wetland habitats sampled using silt-fence arrays, species richness ranged from 22 in inland hydric hammock to 33 in dome swamps. Arrays in forested wetland habitats in TS captured six to 14 fewer species than comparable habitats in SC. Ten fewer species were captured in pine flatwoods and five fewer species in sand pine plantations in TS than in corresponding habitats in SC.

Sampling efficiency and seasonal differences in capture rates—Seasonal capture rates of herpetofauna varied more in SC than in TS, and peak trapping periods varied between study areas (Fig. 2). In SC wetland and terrestrial habitats, peak capture rates occurred in June and August, with a secondary peak in terrestrial habitats during early October (Fig. 2). Weekly capture rates of amphibians in SC were correlated with amount of precipitation in both terrestrial ($F = 44.9$, 20 df, $p < 0.0001$) and wetland ($F = 14.1$, 20 df, $p = 0.001$) habitats, and precipitation explained 69% of the observed variation in amphibian capture rates in terrestrial habitats and 40% in wetland habitats. Peak capture rates in TS wetland habitats occurred from July–early September (when drift fence arrays were not flooded) and in terrestrial habitats from late May–June (Fig. 2). Weekly capture rates of amphibians in TS were correlated with amount of precipitation in terrestrial habitats ($F = 12.4$, 30 df, $p = 0.001$) but not in wetland habitats. During the same survey period (29 May–29 October), 212 mm more rain fell in SC than TS, resulting in longer hydroperiods in similar habitats in SC than TS.

The use of multiple arrays in a habitat type is important in compiling a comprehensive species list and in detecting rare species. In SC wetland habitats sampled by three silt-fence arrays, single arrays captured an average of 54.3% (range 34.8–77.8%) of the number of species documented using all three arrays. In similar TS wetland habitats sampled by two silt-fence arrays, single arrays captured an average of 68.1% (range 55.6–84.6%) of the species documented using both arrays. In the three SC terrestrial habitats sampled by three metal-valley arrays, an average of 65.6% (range 57.1–73.9%)

TABLE 1. Number of captures of herpetofaunal species array-day ^{1} × 100 by drift fence arrays in various habitats in Spring Creek (SC) and Tide Swamp (TS) units of Big Bend WMA, Taylor County, Florida. An X denotes a species observed but not captured by drift fences. Taxa are in accordance with Collins (1997).

	Pine flat-woods	Scrub	Sand-hill	Sand pine plant.	Xeric ham-mock	Dome swamp	Coastal hydric hamm.	Inland hydric hamm.	Basin swamp	Depres-sion marsh	Basin marsh	Tidal marsh
Taxon	SC, TS	TS	SC, TS	SC, TS	SC	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS
Amphibians												
Florida cricket frog (*Acris gryllus dorsalis*)	2.8, 0	0	0,X	7.2, 0	6.1	0, 0	0, 0	0.2, 0	0.6, 0	1.6, 0	0,1.4	0, 0
Mole salamander (*Ambystoma talpoideum*)	0, 0	0	0, 0	0, 0	0.2	0.2, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Two-toed amphiuma (*Amphiuma means*)	0, 0	0	0, 0	0, 0	0	3.3, 0	0.4, 0	0.4, 0	2.0, 0	2.9, 0	1.3, 0.5	0, 0
One-toed amphiuma (*A. pholeter*)	0.2, 0	0	0, 0	0, 0	0	0.4, 0.2	0.9, 0	2.4, 0	1.5, 0.2	0, 0	1.3, 0	0, 0
Oak toad (*Bufo quercicus*)	2.2, 0	0	5.9, 0.5	3.7, 0.5	0.2	0, 0.4	0, 0	0, 0	0, 0	0, 0	0, 0.9	0, 0
Southern toad (*B. terrestris*)	3.0, 2.5	0.2	0.6, 3.4	3.5, 2.6	5.0	3.5, 0.7	0.4, 0.2	1.5, 0.9	4.6, 1.1	0.6, 0	0, 0.5	0, 0
Eastern narrowmouth toad (*Gastrophryne carolinensis*)	8.3, 2.3	0	7.2, 11.7	7.0, 5.6	15.9	6.8, 3.7	8.1, 2.5	11.1, 5.5	7.4, 4.1	0.6, 12.4	2.0, 5.0	0, 0
Cope's gray treefrog (*Hyla chrysoscelis*)	0, 0	0	0, 0	0, 0	0	0.2, 0	0, 0	0.2, 0	0,X	0, 0	0, 0	0, 0
Green treefrog (*H. cinerea*)	0, 0	0	0, 0	0.4, 0.5	1.5	0.4, 0	1.1, 0	0.2, 0	0.2, 0	0, 0	4.6, 0	0, 0
Pinewoods treefrog (*H. femoralis*)	1.1, 0.2	0	3.3, 0	2.4, 0.5	5.4	0.2, 0	0, 0	0, 0	0.2, 0	1.6, 0	0, 0	0, 0
Barking treefrog (*H. gratiosa*)	0.4, 0	0	0, 0.2	0, 0	0.2	0, 0	0, 0	0, 0	0, 0	2.0, 0	0, 0.5	0, 0
Squirrel treefrog (*H. squirella*)	2.4, 0.2	0.2	1.3, 0.2	0.6, 0.2	10.2	0.2, 0.2	0.2, 0.2	1.1, 1.1	0, 0.7	9.5, 4.1	0, 0	0, 0

TABLE 1. Continued.

Taxon	Pine flat-woods	Scrub	Sand-hill	Sand pine plant.	Xeric ham-mock	Dome swamp	Coastal hydric hamm.	Inland hydric hamm.	Basin swamp	Depres-sion marsh	Basin marsh	Tidal marsh
	SC, TS	TS	SC, TS	SC, TS	SC	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS
Central newt (*Notophthalmus viridescens louisianensis*)	0.2, 0	0	0, 0	0, 0	1.3	23.7, 0	0.2, 0	0, 0	5.2, 0.9	3.6, 0.9	0, 0	0, 0
Southern spring peeper (*Pseudacris crucifer bartramiana*)	0, 0	0	0, 0	0, 0	0.2	0, 0	0, 0	0, 0	X, 0	0, 0	0, 0	0, 0
Southern chorus frog (*P. nigrita nigrita*)	0.6, 0	0	0, 0	0, 0.7	0.2	0.2, 0	0, 0	0,X	0, 0	0, 0	0, 0	0, 0
Little grass frog (*P. ocularis*)	2.2, 0	0	0, 0	0.2, 0	1.5	2.2, 0	0, 0	0, 0	0, 0	1.6, 0	0.6, 0	0, 0
Ornate chorus frog (*P. ornata*)	0, 0	0	0, 0	0, 0	0	0, 0	0, 0	0, 0	0.4, 0	X, 0	0, 0	0, 0
Slender dwarf siren (*Pseudobranchus striatus spheniscus*)	0, 0	0	0, 0	0, 0	0	1.3, 0	0, 0	0, 0	0.2, 0	2.9, 0	0, 0	0, 0
Florida gopher frog (*Rana capito aesopus*)	0, 0	0	1.3, 0	0.2, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Bullfrog (*R. catesbeiana*)	0, 0	0	0, 0	0, 0	0	0.6, 0	0.9, 0	0.2, 0	1.5, 0.2	0.3, 0	0, 0	0, 0
Bronze frog (*R. c. clamitans*)	0, 0	0	0, 0	0, 0	0	0, 0	0, 0	0, 0	0, 0.5	0, 0	0, 0	0, 0
Florida leopard frog (*R. s. sphenocephala*)	23.3, 0.5	0.9	10.5, 0.9	12.4, 7.5	21.8	18.1, 2.8	19.6, 3.7	19.8, 5.5	19.0, 25.5	15.4, 6.4	20.3, 13.8	6.5, 0
Eastern spadefoot (*Scaphiopus holbrookii*)	3.3, 0.9	0.4	11.8, 8.7	5.7, 4.2	8.5	0, 0.2	0, 0.5	0, 0.5	1.1, 0.5	0, 0	0, 0	0, 0
Eastern lesser siren (*Siren i. intermedia*)	0, 0	0	0, 0	0, 0	0	0, 0	0, 0	0.4, 0	2.2, 0	0.3, 0	0.6, 0	0, 0

TABLE 1. Continued.

Taxon	Pine flat-woods	Scrub	Sand-hill	Sand pine plant.	Xeric ham-mock	Dome swamp	Coastal hydric hamm.	Inland hydric hamm.	Basin swamp	Depres-sion marsh	Basin marsh	Tidal marsh
	SC, TS	TS	SC, TS	SC, TS	SC	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS
Greater siren (*S. lacertina*)	0, 0	0	0, 0	0, 0	0	0.9, 0	0, 0	0, 0	0.4, 0	0, 0	0, 0	0, 0
Unidentified anuran	1.3, 0.5	0.9	0.6, 1.1	2.0, 0.5	1.3	1.1, 0	1.1, 0	0, 0	0, 0.2	2.6, 0.5	1.3, 0	0.6, 0
Unidentified caudate	0, 0	0	0, 0	0, 0	0	0.4, 0	0, 0	0, 0	0.6, 0	0, 0	0, 0	0, 0
No. amphibians array-day^{-1} × 100	51.4, 7.1	2.8	42.5, 26.6	45.3, 22.7	79.7	64.3, 8.3	32.9, 7.1	37.9, 12.9	47.9, 33.9	45.8, 24.3	32.0, 22.5	7.1, 0
No. amphibian species	13, 6	4	8, 8	11, 9	15	16, 8	9, 5	12, 5	16, 9	13, 4	7, 7	1, 0
Reptiles												
Florida cottonmouth (*Agkistrodon piscivorus conanti*)	0, 0	0	0, 0	0, 0	0	0, 0.2	0, 0	0, 0	0, 0.2	0.6, 0	0.6, 0.9	0, 0
Green anole (*Anolis carolinensis*)	0, 0.7	0.5	0.6, 0.7	0.6, 0.5	0.4	0, 0	0.2, 0.2	0.2, 0.2	0.2, 0	X, 0	X, 0.9	0, 0
Northern scarlet snake (*Cemophora coccinea copei*)	2.0, 1.4	1.8	2.0, 0.5	0.6, 0	0.2	0.2, 0	0, 0.7	0.6, 0	0, 0	0, 0	0, 0	0, 0
Florida snapping turtle (*Chelydra serpentina osceola*)	0, 0	0	0, 0	0, 0	0	0.2, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Six-lined racerunner (*Cnemidophorus s. sexlineatus*)	0.6, 1.1	11.2	14.4, 2.1	1.7, 0.5	0.2	0, 0.5	0, 0.2	0, X	0, 0	0, 0	0, 0	0, 0
Southern black racer (*Coluber constrictor priapus*)	1.3, 0.2	0.7	0.6, 2.3	0.9, 0.9	0.9	0.2, 0.5	0.2, 0.2	0, 0	0.2, 0.2	0, 0	0, 0	0, 0
Eastern diamondback rattlesnake (*Crotalus adamanteus*)	0.2, 0	0	0, 0	0, 0	0	0, 0	X, 0	0, 0	0, 0	0, 0	0, 0	0, 0

TABLE 1. Continued.

	Pine flat-woods	Scrub	Sand-hill	Sand pine plant.	Xeric ham-mock	Dome swamp	Coastal hydric hamm.	Inland hydric hamm.	Basin swamp	Depres-sion marsh	Basin marsh	Tidal marsh
Taxon	SC, TS	TS	SC, TS	SC, TS	SC	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS
Southern ringneck snake (*Diadophis p. punctatus*)	0, 0	0	0, 0.2	0, 0	0	0, 0	0, 0	0.2, 0	0.2, 0	0, 0	0, 0	0, 0
Corn snake (*Elaphe guttata*)	0, 0.2	0	0, 0.2	0, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Gray rat snake (*E. obsoleta spiloides*)	0, 0.5	0.2	0, 0	0, 0	0.4	0.2, 0	0, 0	0.6, 0.5	0.4, 0.2	0.3, 0	0, 0	0, 0
Northern mole skink (*Eumeces egregius similis*)	0, 0	0	0.6, 0	1.3, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Five-lined skink (*E. fasciatus*)	0, 0	0	0, 0	0, 0	0.2	1.1, 0.7	0.6, 0.7	0.9, 0.2	0, 0	0.3, 0	0, 0	0, 0
Southeastern five-lined skink (*E. inexpectatus*)	0.2, 0	0.2	0, 0	0, 0	0.2	0, 0	0, 0.2	0, 0	0, 0	0.3, 0	0, 0	0, 0
Broadhead skink (*E. laticeps*)	1.1, 0.5	0	0, 0	0, 0.5	4.4	3.0, 2.5	4.4, 1.6	1.3, 3.2	0.6, 0.2	0.6, 0	0, 0	0, 0
Gopher tortoise (*Gopherus polyphemus*)	0, 0	0	2.0, 0	0.2, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Eastern mud snake (*Farancia a. abacura*)	0, 0	0	0, 0	0, 0	0	0.4, 0	0, 0	0, 0	0.4, 0.2	0.6, 0.5	0, 0	0, 0
Striped mud turtle (*Kinosternon baurii*)	0.4, 0	0	0, 0	0, 0	0	0.6, 0	0, 0	1.5, 0	0.6, 1.4	2.9, 0.5	0.6, 0.5	1.2, 0
Eastern mud turtle (*K. subrubrum* ssp.)	0.4, 0	0	0, 0	0, 0	0	3.3, 0.5	0.4, 0	0.6, 0	1.5, 0.5	6.9, 1.4	0, 0	0, 0
Eastern kingsnake (*Lampropeltis g. getula*)	0, 0	0	0, 0	0, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0.6, 0	0, 0
Scarlet kingsnake (*L. triangulum elapsoides*)	0, 0	0.5	0, 0.2	0, 0	0.2	0, 0.2	0.2, 0.2	0.6, 0	0, 0.2	0, 0	0, 0	0, 0

TABLE 1. Continued.

Taxon	Pine flat-woods	Scrub	Sand-hill	Sand pine plant.	Xeric ham-mock	Dome swamp	Coastal hydric hamm.	Inland hydric hamm.	Basin swamp	Depres-sion marsh	Basin marsh	Tidal marsh
	SC, TS	TS	SC, TS	SC, TS	SC	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS
Eastern coachwhip (*Masticophis f. flagellum*)	0, 0	0.2	0, 0.5	0.2, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Eastern coral snake (*Micrurus fulvius*)	0, 0	0	0, 0.2	0.2, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Gulf salt marsh snake (*Nerodia c. clarkii*)	0, 0	0	0, 0	0, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0.7
Banded water snake (*N. f. fasciata*)	0, 0	0	0, 0	0, 0	0	0, 0.2	0.2, 0.2	0.6, 0	1.5, 0.5	0.3, 0	0.6, 0.5	0, 0
Rough green snake (*Opheodrys aestivus*)	0, 0	0	0, 0.2	0, 0	0	0, 0	0.4, 0	0, 0	0, 0	0, 0.5	0, 0	0, 0
Eastern glass lizard (*Ophisaurus ventralis*)	0.6, 0.9	0.2	0, 0	0, 0	0	0.9, 0	0, 0.7	0, 0	0, 0.2	0, 0	0.6, 0.5	0, 0
Florida pine snake (*Pituophis melanoleucus mugitus*)	0, 0.2	0	0, 0	0, 0	0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Striped crayfish snake (*Regina alleni*)	0, 0	0	0, 0	0, 0	0	0, 0	0, 0	0, 0	0, 0	0.3, 0	0, 0	0, 0
Glossy crayfish snake (*R. r. rigida*)	0, 0	0	0, 0	0, 0	0	0.4, 0	0, 0	0, 0	0, 0	0, 0	0.6, 0	0, 0
Southern fence lizard (*Sceloporus u. undulatus*)	0.9, 3.2	3.2	2.0, 8.9	2.4, 3.3	0.4	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Ground skink (*Scincella lateralis*)	0, 0.2	0	0, 0.2	0.2, 0.2	2.0	0.9, 0.5	2.2, 0.2	0, 0.7	0, 0	0, 0	0.6, 0	0, 0
North Florida swamp snake (*Seminatrix p. pygaea*)	0.2, 0	0.2	0, 0	0, 0	0	0.6, 0	0, 0	0, 0	0, 0	0.6, 0	0, 0.9	0, 0
Dusky pigmy rattlesnake (*Sistrurus miliarius barbouri*)	1.3, 0.2	0.2	0, 0.9	0.4, 0.5	0.2	0.4, 0	0.2, 0	0, 0.5	0.2, 0.2	0, 0	0, 0	0, 0

TABLE 1. Continued.

	Pine flat-woods	Scrub	Sand-hill	Sand pine plant.	Xeric ham-mock	Dome swamp	Coastal hydric hamm.	Inland hydric hamm.	Basin swamp	Depres-sion marsh	Basin marsh	Tidal marsh
Taxon	SC, TS	TS	SC, TS	SC, TS	SC	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS	SC, TS
Common musk turtle (*Sternotherus odoratus*)	0, 0	0	0, 0	0, 0	0	0.2, 0	0, 0	0, 0	0.4, 0	0, 0	0, 0	0, 0
Florida redbelly snake (*Storeria occipitomaculata obscura*)	0.2, 0	0	0, 0	0, 0.2	1.3	0.2, 0	0.2, 0	0, 0	0.2, 0	0, 0	0, 0	0, 0
Florida box turtle (*Terrapene carolina bauri*)	0, 0	0	X, 0	0, 0	0	X, X	X, 0	0, 0	X, 0	0, 0	0, 0	0, 0
Bluestripe ribbon snake (*Thamnophis sauritus nitae*)	0.4, 0	0.9	0, 0	0.2, 0	0	0.6, 0.5	0.4, 0	0.2, 0	0, 0	1.0, 0.5	2.0, 0.5	0, 0
Bluestripe garter snake (*T. sirtalis similis*)	0.4, 0	0	0, 0	0, 0.5	0.2	0, 0.5	1.7, 0	0.4, 0.2	0, 0.2	0, 0	2.0, 0	0.6, 0
Yellowbelly slider (*Trachemys s. scripta*)	0, 0	0	0, 0	0, 0	0	0, 0	X, 0	0, 0	0, 0	0, 0	0, 0	0, 0
Unidentified lizard	0, 0	0	0, 0	0, 0	0	0, 0	0, 0.2	0, 0.2	0, 0	0, 0	0, 0	0, 0
Unidentified snake	0, 0	0.2	0, 0.2	0, 0	0	0.4, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
No. reptiles array-day^{-1} × 100	10.5, 9.4	20.2	22.2, 17.4	9.2, 7.0	11.3	14.2, 9.7	11.5, 5.3	7.4, 5.7	5.2, 4.1	15.0, 4.7	8.5, 4.6	1.8, 0.7
No. reptile species	15, 12	13	7, 14	12, 9	14	17, 11	13, 10	11, 8	11, 12	12, 5	9, 7	2, 1

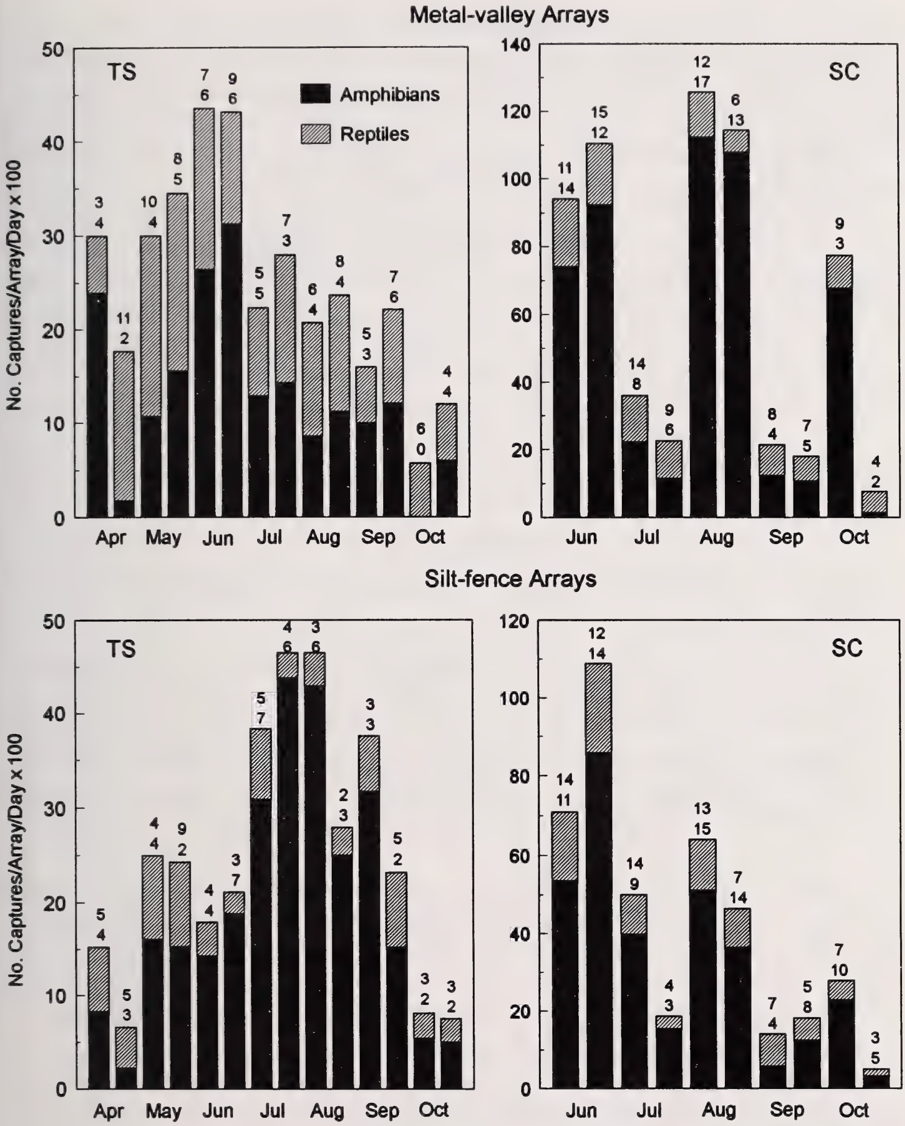


FIG. 2. Bimonthly capture rates for amphibians and reptiles during 1992 in Spring Creek (SC) and during 1993 in Tide Swamp (TS), Taylor County, FL. Numbers above the bars refer to the number of species of reptiles (top) and amphibians (bottom) captured bimonthly. Terrestrial habitats were surveyed with metal-valley arrays and wetland habitats with silt-fence arrays.

of the species were captured by only one array. In the five TS terrestrial habitats sampled by two metal-valley arrays, an average of 67.5% (range 58.8–88.9%) of the species were captured by a single array.

When the cumulative number of species captured over time is plotted, there is typically an initial sharp peak in the number of species followed by a tapering off, although occasional peaks will occur later as species with marked seasonal activity patterns appear, such as winter-breeding amphibians. A decrease in the slope of the line of cumulative captures over time indicates that the number of species potentially trappable by drift fence arrays has been approached for a given habitat.

During the first month of trapping, we captured 79.7% of the total species (N = 59) that would eventually be captured from all habitats in SC but only 60.0% of the eventual number of species (N = 45) in TS. An average of 59.4% (range 46.4–72.7%) of the total number of species captured in each SC habitat type were recorded during the first month of trapping (June), and an average of 71.2% (range 56.5–82.8%) were captured by the second month (Fig. 3). Over 160 mm of rain fell on 14–15 August 1992, providing a dramatic example of the effect of weather on capture data. After the storm, 388 individuals of 33 species were found in the traps, including six new species in mesic flatwoods and dome swamp and seven new species in coastal hydric hammock and basin swamp (Fig. 3), all of which flooded. New species were captured at a slower rate in TS than in SC, and there was less of an initial peak (Fig. 3). For the eight TS habitats sampled using two drift fence arrays (excluding tidal marsh), an average of only 31.1% (range 21.4–38.5%) of the species that would eventually be captured in each habitat were trapped during the first month (April), and an average of 50.3% (range 41.2–57.9%) were captured by the second month (Fig. 3). During October, the last month of trapping, new species accounted for an average of only 5.9% (range 0–13.6%) and 2.6% (range 0–9.5%) of the total number of species captured in each habitat type in SC and TS, respectively.

Species composition and relative abundance in relation to habitats and study areas—We captured 1,916 amphibians and 414 reptiles in SC and 632 amphibians and 350 reptiles in TS. The Florida leopard frog, which comprised 29.0% of all captures, was found everywhere except in SC tidal marshes (Table 1). Of the other four most frequently captured species, the eastern narrowmouth toad (15.0% of all captures) and southern toad (4.6%) were habitat generalists. The eastern spadefoot (5.1% of all captures) was primarily restricted to terrestrial habitats, and 71.2% of all central newts (4.7%) came from SC dome swamps (Table 1); no newts were in the eft stage.

The proportions of aquatic, semiaquatic, terrestrial, fossorial, and arboreal species in comparable habitats were compared between study areas using Chi-square analyses. The herpetofaunal community composition of mesic flatwoods ($\chi^2 = 77.2$, 4 df, $p < 0.0001$) and sandhills ($\chi^2 = 27.9$, 3 df, $p < 0.0001$) differed between study areas, but the composition of sand pine plantations did not differ significantly ($\chi^2 = 6.27$, 3 df, $p = 0.10$). Differences in precipitation during the two surveys probably accounted for observed differences in community composition of mesic flatwoods and sand-

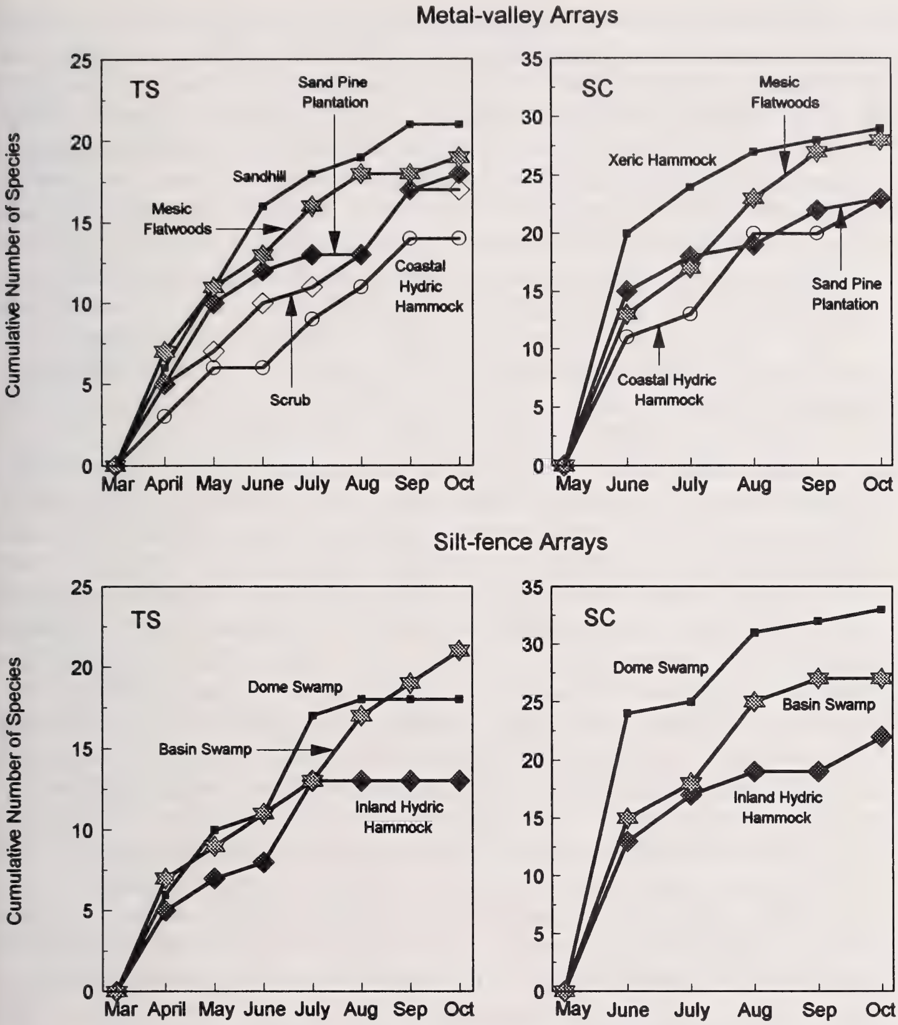


FIG. 3. Cumulative number of species of amphibians and reptiles captured month^{-1} using three arrays per habitat type in 1992 in Spring Creek (SC) and two arrays per habitat type in 1993 in Tide Swamp (TS), Taylor County, FL. Terrestrial habitats were surveyed with funnel and pitfall traps along metal-valley drift fences, and wetland habitats were surveyed with only funnel traps along silt fences.

hills. In mesic flatwoods, aquatic and semiaquatic species accounted for 51% of the herpetofaunal captures in SC but <3% in TS. In the drier conditions present in TS, semiaquatic species accounted for 27% of captures in sand pine plantations but only 2% of captures in sandhills. In both study areas, semiaquatic species (primarily anurans) were more dominant in sand pine plantations than in sandhill or scrub habitat. Approximately 50% of captures in TS mesic flatwoods and sandhills were terrestrial (surface- and refugiadwelling) species, but arboreal species were more dominant in flatwoods (41% of captures) and fossorial species in sandhills (20% of captures). In SC sandhills, terrestrial and fossorial species accounted for 47% and 24% of captures, respectively, but semiaquatic species were also important (18% of captures). In terrestrial habitats in both study areas, arboreal species accounted for 10–24% of captures, except for TS mesic flatwoods where they accounted for 41% of captures. Semiaquatic, terrestrial, and arboreal species each comprised 26–33% of all captures in SC xeric hammock.

The greater proportion of aquatic and semiaquatic species in most wetland habitats in SC than in TS was primarily responsible for significant differences in community composition between study areas in inland ($\chi^2 = 32.8$, 4 df, $p < 0.0001$) and coastal ($\chi^2 = 19.8$, 4 df, $p = 0.0005$) hydric hammocks, dome swamps ($\chi^2 = 49.0$, 4 df, $p < 0.0001$), basin swamps ($\chi^2 = 31.5$, 4 df, $p < 0.0001$), and depression marshes ($\chi^2 = 68.6$, 3 df, $p < 0.0001$). The community composition of basin marshes was not significantly different ($\chi^2 = 6.56$, 3 df, $p = 0.09$) between study areas, but the power of the test was low (0.55). Aquatic/semiaquatic species accounted for a larger percentage of the herpetofaunal community of wetland habitats in SC than in TS: inland hydric hammock (59% vs. 30%), coastal hydric hammock (57% vs. 30%), dome swamp (75% vs. 32%), basin marsh (78% vs. 69%), and depression marsh (72% vs. 37%). Only basin swamps had a greater proportion of aquatic/semiaquatic species in TS (79%) than in SC (70%), but 15% of all captures in SC basin swamps were aquatic species compared to only 1% in TS. The short hydroperiods exhibited by most TS wetlands resulted in greater representation by terrestrial and arboreal species. For example, terrestrial species comprised 48% and 35% of captures in TS dome swamps and freshwater marshes, respectively, compared to only 19% and 6% of captures in the same SC habitats. Arboreal species accounted for 5–26% of all captures in wetland habitats in both study areas, with resident treefrogs, lizards, and snakes accounting for most captures in forested wetlands, and breeding or newly metamorphosed treefrogs predominating in marshes. The eastern spadefoot accounted for all captures ($\leq$4%) of fossorial species in wetland habitats.

Almost twice as many amphibians and over three times as many reptiles were captured per array-day in depression marshes in SC as in TS (Table 1). Depression marsh arrays were flooded from June–October in SC but lacked standing water from June–August in TS. Nineteen individuals of three aquatic salamander species (two-toed amphiuma, slender dwarf siren, eastern lesser siren) and 40 breeding or newly metamorphosed treefrogs (pinewoods, barking, squirrel) were captured in the two SC depression marshes compared to only nine squirrel treefrogs in the TS depression marsh. The greater abundance of mud turtles in depression marshes in SC than TS accounted for the disparity in reptile capture rates.

The capture rate for amphibians and reptiles in the SC basin marsh was less than twice that in the TS basin marsh, and species richness was comparable. Basin marshes had longer hydroperiods than depression marshes and were apparently seldom utilized by most hylid species, except the green treefrog, whereas the Florida leopard frog comprised >60% of amphibian captures. In basin swamps, capture rates for amphibians and reptiles were comparable between study areas (Table 1), although only one aquatic salamander was captured in TS compared to 32 individuals of five species in SC. Comparable numbers of aquatic and semiaquatic reptiles were captured in basin swamps in both study areas. The only captures in TS tidal marshes were three Gulf salt marsh snakes, whereas arrays in the more inland SC tidal marshes, which had brackish water, captured Florida leopard frogs, striped mud turtles, and a bluestripe garter snake.

Capture rates for amphibians were 2.9 to 7.7 times higher in SC than in TS in dome swamp, coastal hydric hammock, and inland hydric hammock (Table 1), all of which lacked standing water in TS during much of the study. Arrays in these three habitats in SC captured 48 aquatic salamanders of five species, whereas only one aquatic salamander was captured in TS. Reptile capture rates in these habitats were 1.3 to 2.2 times higher in SC than in TS (Table 1), most of the difference being accounted for by the prevalence of aquatic and semiaquatic reptiles in SC. Reptiles were proportionally a larger component of herpetofaunal captures in terrestrial habitats in TS than in SC (Fig. 2).

Amphibian capture rates in pineland habitats were consistently higher in SC than in TS (Table 1). Differences in amphibian capture rates between study areas was most noticeable in mesic flatwoods, the wettest pineland habitat. Over seven times as many individual amphibians were captured per array-day (primarily because of an abundance of Florida leopard frogs) and over twice as many amphibian species were captured in flatwoods in SC than in TS. In TS, sandhill arrays captured 3.7 times more amphibians per array-day and two more species than flatwoods arrays. Reptile capture rates and species richness were comparable between TS scrub and sandhill, but six-lined racerunners and southern fence lizards dominated scrub and sandhill, respectively. Scrub habitat had a depauperate amphibian fauna. Reptile capture rates were approximately twice as high in sandhill habitats as in mesic flatwoods in both study areas (Table 1).

Captures in SC sand pine plantations included characteristic xeric upland herpetofauna, such as the oak toad, gopher frog, gopher tortoise, northern mole skink, southern fence lizard, and eastern coachwhip. Florida cricket frogs were surprisingly abundant in SC sand pine plantations, and four of the eight southern chorus frogs captured came from TS sand pine plantations. In both study areas, capture rates for amphibians were comparable between sand pine plantations and sandhills, but reptile capture rates were ca. 2.5 times higher in sandhills (Table 1).

The SC xeric hammock sites were in the proximity of water, which probably helped account for the diverse and abundant amphibian community that included four species of *Hyla* and three species of *Pseudacris,* which are usually under-sampled during drift fence surveys. The capture rate for amphibians was higher in xeric hammock than in any other habitat in SC. The reptile community in xeric hammock was also diverse, but the capture rate was comparable to or less than in pineland habitats (Table 1).

DISCUSSION—*Success of the herpetofaunal inventory*—The study yielded nine new records for Taylor County: two-toed amphiuma, one-toed amphiuma, central newt, Cope's gray treefrog, Florida gopher frog, six-lined racerunner, five-lined skink, eastern coachwhip, and striped crayfish snake (Ashton and Ashton, 1988, 1991a, and 1991b). We failed to find six of 12 species that have range limits approaching the Big Bend region, potentially occur in the habitat types sampled, and are susceptible to capture by drift fences. Only one of these species, the Florida worm lizard (*Rhineura floridana*), has been reported from Taylor County (Wood, 1995). We also failed to find one salamander, one frog, and five snake species reported from Taylor County that potentially occur in habitats sampled in the Big Bend WMA. Our lack of success in capturing the Florida crowned snake (*Tantilla relicta*), which is the most common snake species captured in xeric habitats during most drift fence surveys in peninsular Florida (e.g., Florida Game and Fresh Water Fish Commission, 1976; Campbell and Christman, 1982b; Mushinsky, 1985; Christman, 1988; Greenberg et al., 1994; Franz et al., 1995), appears to confirm its previously documented distribution (Ashton and Ashton, 1988; Conant and Collins, 1991).

Our drift fence survey yielded comparable numbers of native species (24 amphibian and 39 reptile) to other drift fence surveys sampling both terrestrial and wetland habitats in the eastern portion of Florida's panhandle. Twenty-nine amphibian and 36 reptile species were trapped at St. Mark's National Wildlife Refuge (NWR), Wakulla County (U.S. Fish and Wildlife Service, 1980), and 29 amphibian and 35 reptile species were trapped at Joe Budd and Talquin WMAs, Leon and Gadsden counties (K. Enge, unpubl. data). Ten species were captured at St. Mark's NWR but not in our study areas (eight of which probably occurred there), and vice versa. Drift fence surveys farther south in Florida's peninsula yielded fewer native species, partly because of the documented southward decline in native herpetofaunal species (Duellman and Schwartz, 1958; Kiester, 1971; Means and Simberloff, 1987; Auth, 1989). For example, only 11 native amphibian and 24 reptile species were trapped in Everglades National Park, Dade County (Dalrymple, 1988), and 14 amphibian and 26 reptile species in Jonathan Dickinson State Park, Martin County (Timmerman et al., 1994).

In a drift fence survey conducted from 17 December 1991–8 February 1992 in Econfina River State Park in Taylor County, 80.9% of all herpetofaunal captures (N = 178, 11 species) were winter-breeding amphibian species: mole salamander, southern spring peeper, southern chorus frog, ornate chorus frog, and Florida leopard frog (K. Studenroth, Florida Dept. Environ. Prot., unpubl. data). Southern chorus frogs accounted for 43.8% of all captures in Econfina River State Park but only for 0.2% of all captures (N = 3,341) from our two study areas. These findings emphasize the importance of conducting studies throughout the year to obtain valid herpetofaunal relative abundance data for an area.

Comparisons of capture rates between study areas—The two study areas had similar elevation and habitat types, although the proportional coverage of habitats differed. Management practices (e.g., prescribed burning), logging history, recreational use, road development, and presence of drainage ditches were also similar. Comparisons of herpetofaunal capture rates among habitats in SC and TS are complicated by differences in the length of trapping periods. The increased likelihood of detecting additional species by the use of an extra array per habitat type in SC apparently was offset in TS by the longer sampling period; however, as noted above, the length of sampling period becomes less important after the initial period of one or two months. We suspect that the use of multiple arrays is most critical in wetland habitats subject to variability in water depth and hydroperiod (e.g., dome swamp), and in terrestrial habitats with heterogeneous microhabitat features and/or widely scattered wetlands.

The consistently higher amphibian capture rates in pineland habitats in SC than in TS was probably related to greater precipitation during the SC survey stimulating amphibian movements and increasing reproductive success of summer-breeding species, especially terrestrial ones dependent upon ephemeral wetlands for breeding (Moler and Franz, 1987; Pechmann et al., 1989; Dodd, 1992; LaClaire and Franz, 1990). Higher amphibian capture rates in TS sandhills than flatwoods was probably related to lower precipitation having a more inhibitory effect on movements of semiaquatic amphibian species, which are a major component of flatwoods fauna, than on the more xeric-adapted amphibian fauna (e.g., eastern spadefoot) typical of sandhill habitat.

Herpetofaunal differences between forested wetland habitats in the two study areas were partially accounted for by differences in hydroperiods and water levels. Capture rates of amphibians and reptiles were higher in the three habitats with the shortest hydroperiods (dome swamp, coastal hydric hammock, and inland hydric hammock) in SC than in TS because of the prevalence of aquatic and semiaquatic species in SC. Like depression marshes, dome swamps provide important breeding habitat for many anurans that require isolated ephemeral ponds (Harris and Vickers, 1984; Enge and Marion, 1986). The herpetofaunal communities of coastal and inland hydric hammocks within a study area were similar, despite differences in vegetative physiognomy. Aquatic amphibians and reptiles were captured in SC hydric hammocks following heavy rains that briefly flooded the surface. During high water, one-toed amphiumas apparently occasionally moved from their favored muck microhabitats (Means, 1992) in basin swamps and hydric hammocks into adjacent habitats such as mesic flatwoods.

Longer hydroperiods resulted in the capture of more aquatic herpetofauna in SC than in TS. Aquatic salamanders and turtles were often captured when traps were completely submerged during high-water conditions, whereas most anurans and snakes were captured when traps were only partially submerged and effective at catching animals swimming on the surface of the water.

We captured 218 treefrogs in the Big Bend WMA, despite the relative ineffectiveness of drift fences in capturing arboreal anurans (Gibbons and Bennett, 1974; Gibbons and Semlitsch, 1982; Dodd, 1991; however, see Murphy, 1993). Most of the treefrogs captured were species (e.g., pinewoods, squirrel, barking) that typically breed in small, isolated wetlands; however, seven of the eight treefrogs captured in basin marshes were green treefrogs, which prefer breeding in permanent marshes (Moler and Franz, 1987). Some of the basin marshes surveyed may have been slightly brackish, which might have affected the presence or abundance of amphibians, although the Florida leopard frog is known to be tolerant of brackish water (Neill, 1958; Christman, 1974). Depression marshes provide more suitable breeding sites for amphibians with relatively short larval periods (e.g., eastern narrowmouth toad, eastern spadefoot, oak toad, pinewoods treefrog, barking treefrog) than do basin marshes because the shorter hydroperiod results in a lack or scarcity of fish and other large predators (Moler and Franz, 1987; LaClaire and Franz, 1990), and larval amphibians possibly have an initial size advantage over invertebrate predators when wetlands flood (Wilbur, 1980).

Comparisons of species richness between study areas and with other studies—Comparisons of species richness based on captures in drift fence arrays among different habitats within a study area may be complicated by behavioral differences of the same species in different habitats. Habitat differences (e.g., hydroperiod, vegetative physiognomy, soil exposure, insolation) may influence the degree to which a species moves or exhibits arboreal, terrestrial, or fossorial activity, thereby affecting the likelihood of individuals encountering drift fences.

Trapping in SC typically yielded more species per habitat than trapping in TS; however, one less array was used in most TS habitats. This lack of an array may have been more critical in structurally variable habitats, especially ones in a complex landscape mosaic, because of the reduced probability of sampling productive microhabitats where additional species could be detected. Precipitation differences may have contributed to the observed difference in species richness between the two study areas because wetland habitats flooded during the SC survey but dried during the TS survey. Proportionally fewer of the final species' totals per habitat were detected during the first month of trapping in TS than in SC. This lower initial trapping success in TS can probably be attributed to fewer arrays and initiation of sampling before peak activity periods for many species or during weather conditions that were less conducive to animal movements. We targeted the warmer months for our surveys to maximize trapping efficiency, but by doing so, we under-sampled or missed amphibian species that typically breed or are more active during the cooler months.

Species richness in most habitats in the Big Bend WMA was lower or similar to that found in other drift fence studies in similar habitats in northern Florida (e.g., Florida Game and Fresh Water Fish Commission, 1976; U.S. Fish and Wildlife Service, 1978 and 1980; Campbell and Christman, 1982b; Labisky et al., 1983; Vickers et al., 1985; Enge and Marion, 1986; Joiner and Godwin, 1992a, 1992b, and 1992c); however, our surveys lasted for shorter periods of time than most other studies.

Sixteen more species of amphibians and reptiles were captured in depression marshes in SC than in TS, and at least nine more species were captured in SC depression marshes than in the basin marsh in either study area (Table 1). Species occurrence in a particular marsh was probably related to brackish-water influence in coastal areas, hydroperiod length, water depth, surrounding habitat, and seasonality of trapping. Species trapped included aquatic year-round residents (even when the marshes dried), terrestrial amphibians that used marshes only as breeding sites, and some reptiles that seasonally used marshes as foraging sites. We captured six species (southern toad, pinewoods treefrog, gray rat snake, five-lined skink, broadhead skink, rough green snake) in marshes that were not captured during other drift fence surveys of marshes, but other surveys captured 11 additional species (Joiner and Godwin, 1992a and 1992b). Tidal marshes had the lowest herpetofaunal species richness of any habitat surveyed.

We captured 13 amphibian and 13 reptile species in inland hydric hammocks and 10 amphibian and 17 reptile species in coastal hydric hammocks (Table 1), which was similar or higher diversity than other drift fence surveys of hydric hammocks in northern Florida (U.S. Fish and Wildlife Service, 1980; Joiner and Godwin, 1992a and 1992c). The species richness of amphibians (18) and reptiles (22) in dome swamps in the Big Bend WMA was comparable to that in six dome swamps in Bradford County (Vickers et al., 1985), although species composition differed, possibly because of regional or seasonal differences.

Other drift fence surveys in wet or mesic flatwoods in northern peninsular or northwestern Florida (e.g., U.S. Fish and Wildlife Service, 1978 and 1980; Labisky et al., 1983; White, 1983; Enge and Marion, 1986; K. Enge, unpubl. data) captured eight to 15 amphibian and 19 to 26 reptile species compared to 13 amphibian and 20 reptile species in the Big Bend WMA (Table 1). The scarcity of refugia, ground-level structural diversity, and stand heterogeneity in our flatwoods sites, which were bedded slash pine plantations, may have contributed to their relatively low reptile species diversity. In slash or longleaf pine plantations on sandhill sites, we captured nine amphibian and 15 reptile species compared to four to 12 amphibian and 12 to 17 reptile species in other sandhill studies in northern Florida (U.S. Fish and Wildlife Service, 1978 and 1980; Joiner and Godwin, 1992c). Herpetofaunal diversity was relatively high in Big Bend WMA sandhills considering the limited sampling conducted and altered habitat conditions of the sites. The increased ground cover and understory vegetation resulting from clearcutting probably lasts longer in slash pine plantations on sandhill sites than on flatwoods sites because of poor growth and survival of pines (Umber and Harris, 1974), but the destruction of wiregrass during logging and site preparation may drastically alter the sandhill community by decreasing the frequency of fire (Noss, 1988).

We captured 15 amphibian species in the SC xeric hammock (Table 1), whereas longer studies in xeric hammocks in Putnam (Franz et al., 1995) and Levy (K. Enge, unpubl. data) counties yielded only eight and five amphibian species, respectively. Reptile species richness was comparable (11–15 species) among the three studies. The abundance of amphibian species in the SC xeric hammock was probably attributable to the presence of nearby wetlands and abundant precipitation. There were no nearby wetlands in Levy County, and Putnam County was experiencing a drought. Scrub habitat in TS had one-half as many amphibian species as any other xeric upland habitat surveyed, but reptile species richness was comparable. These pioneer scrubs were not as biologically diverse as the ancient scrubs along the central ridge of the peninsula and lacked the characteristic endemic species (see Christman, 1988; Mushinsky and McCoy, 1995).

Planting of sand pines on sandhill sites requires less intensive site preparation, and higher pine survival and growth rates typically result in more rapid canopy closure and less shrubs and ground cover in sand pine plantations than in other southern pine plantations. Despite the barren appearance of sand pine plantations in the Big Bend WMA, they contained a diverse herpetofauna that included many anurans, which may have been attracted to the shaded conditions that presumably increased the relative humidity and soil moisture levels. Amphibian species richness in sand pine plantations was comparable to that in TS sandhill habitat and higher than in TS scrub and SC sandhill, although the lower amphibian species richness in the latter habitat was probably an artifact of lower sampling intensity (i.e., two fewer arrays). Reptile species richness tended to be lower in sand pine plantations than in sandhills, which was not surprising considering the reduced light penetration in plantations and lack of structural diversity and ground-level heterogeneity.

ACKNOWLEDGMENTS—We would like to thank Ken Benfield, David Cook, Jim Garrison, Christine Goff, Patrick Jodice, Patricia MacLaren, Doug Runde, Chuck McKelvy, Juanita McWatters, Jeff Norment, Fanny Valentine, Steve Stiegler, Art Stockle, Harry Dutton, Sammy Patrick, and David McDuffie for their able assistance in the field or making funnel traps. The studies would not have been possible without the approval and support of the Florida Game and Fresh Water Fish Commission. David Cobb, Brian Millsap, Don Wood and three anonymous reviewers reviewed drafts of this manuscript.

LITERATURE CITED

Ashton, R. E., Jr. and P. S. Ashton. 1988. Handbook of Reptiles and Amphibians of Florida. Part 1. The Snakes. Windward Publ., Inc., Miami, FL. 176 pp.

——— and P. S. Ashton. 1991a. Handbook of Reptiles and Amphibians of Florida. Part 2. Lizards, Turtles and Crocodilians. Windward Publ., Inc., Miami, FL. 191 pp.

——— and P. S. Ashton. 1991b. Handbook of Reptiles and Amphibians of Florida. Part 3. The Amphibians. Windward Publ., Inc., Miami, FL. 191 pp.

Auth, D. L. 1989. Amphibian and reptilian density in Florida counties. Gainesville Herp. Soc. Newsl. 5(8):7–14.

Bechtold, W. A., M. J. Brown, and R. M. Sheffield. 1990. Florida's forests, 1987. USDA For. Serv., S.E. For. Expt. Sta. Resour. Bull. SE-110, Asheville, NC.

Campbell, H. W. and S. P. Christman. 1982a. Field techniques for herpetofaunal community analysis. Pp. 193–200. *In*: Scott, N. J., Jr. (ed.). Herpetological Communities. U.S. Fish Wildl. Serv, Wildl. Res. Rept. No. 13.

——— and S. P. Christman. 1982b. The herpetofaunal components of Florida sandhill and sand pine scrub associations. Pp. 163–171. *In*: Scott, N. J., Jr. (ed.). Herpetological Communities. U.S. Fish Wildl. Serv., Wildl. Res. Rept. No. 13.

Christman, S. P. 1974. Geographic variation for salt water tolerance in the frog *Rana sphenocephala.* Copeia 1974:773–778.

———. 1988. Endemism in Florida's interior sand pine scrub. Florida Game and Fresh Water Fish Comm., Nongame Wildl. Prog. Final Rept., Tallahassee, FL.

Collins, J. T. 1997. Standard common and current scientific names for North American amphibians and reptiles (4th Edition). Soc. Study Amphibians and Reptiles Herp. Circ. No. 25. 40 pp.

Conant, R. and J. T. Collins. 1991. A Field Guide to Amphibians and Reptiles of Eastern and Central North America (3rd Edition). Houghton Mifflin Co., Boston, MA. 450 pp.

Corn, P. S. 1994. Straight-line drift fences and pitfall traps. Pp. 109–117. *In*: Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster (eds.). Measuring and Monitoring Biological Diversity: Standard Methods Amphibians. Smithsonian Inst. Press, Washington, D.C.

Dalrymple, G. H. 1988. The herpetofauna of Long Pine Key, Everglades National Park, in relation to vegetation and hydrology. Pp. 72–86. *In*: Szaro, R. C., K. E. Severson, and D. R. Patton (eds.). Management of Amphibians, Reptiles, and Small Mammals in North America. U.S. Dept. Agric. For. Serv. Gen. Tech. Rept. RM-166.

Dodd, C. K., Jr. 1991. Drift fence-associated sampling bias of amphibians at a Florida sandhills temporary pond. J. Herp. 25:296–301.

———. 1992. Biological diversity of a temporary pond herpetofauna in north Florida sandhills. Biodivers. and Conserv. 1:125–142.

Duellman, W. E. and A. Schwartz. 1958. Amphibians and reptiles of southern Florida. Bull. Florida State Mus., Biol. Sci. 3:181–324.

Enge, K. M. 1997. Use of silt fences and funnel traps for drift fences. Herp. Rev. 28:30–31.

——— and W. R. Marion. 1986. Effects of clearcutting and site preparation on herpetofauna of a north Florida flatwoods. For. Ecol. Manage. 12:177–192.

Florida Game and Fresh Water Fish Commission. 1976. Cross Florida barge canal restudy report: wildlife study. Volume 1. Appendix B: Herpetology study. Dept. Army Corps of Eng., Jacksonville, FL.

Florida Natural Areas Inventory. 1990. Guide to the natural communities of Florida. Florida Nat. Areas Inventory and Florida Dept. Nat. Resour., Tallahassee, FL.

Franz, R., R. E. Ashton, and W. W. Timmerman. 1995. Behavior and movements of certain small sandhill amphibians and reptiles in response to drift fences. Florida Game and Fresh Water Fish Comm., Nongame Wildl. Prog. Proj. Rept., Tallahassee, FL.

Gibbons, J. W. and D. H. Bennett. 1974. Determination of anuran terrestrial activity patterns by a drift fence method. Copeia 1974:237–243.

——— AND R. D. SEMLITSCH. 1982. Terrestrial drift fences with pitfall traps: an effective technique for quantitative sampling of animal populations. Brimleyana 7:1–16.

GREENBERG, C. H., D. G. NEARY, AND L. D. HARRIS. 1994. Effect of high-intensity wildfire and silvicultural treatments on reptile communities in sand-pine scrub. Conserv. Biol. 8: 1047–1057.

HARRIS, L. D. AND C. R. VICKERS. 1984. Some faunal community characteristics of cypress ponds and the changes induced by perturbations. Pp. 171–185. *In*: EWEL, K. C. AND H. T. ODUM (eds.). Cypress Swamps. Univ. Presses Florida, Gainesville, FL.

JOINER, N. D. AND J. GODWIN. 1992a. Aquatic and terrestrial wildlife surveys for the Crystal River watershed. Fourth quarterly report. Prepared for SWIM Dept., Southwest Florida Water Manage. Dist., Contract No. 89093. Florida Game and Fresh Water Fish Comm., Nongame Wildl. Prog., Tallahassee, FL.

——— AND J. GODWIN. 1992b. Aquatic and terrestrial wildlife surveys for the Lake Panasoffkee watershed. Fourth quarterly report. Prepared for SWIM Dept., Southwest Florida Water Manage. Dist., Contract No. 89093. Florida Game and Fresh Water Fish Comm., Nongame Wildl. Prog., Tallahassee, FL.

——— AND J. GODWIN. 1992c. Aquatic and terrestrial wildlife surveys for the Rainbow River watershed. Fourth quarterly report. Prepared for SWIM Dept., Southwest Florida Water Manage. Dist., Contract No. 89093. Florida Game and Fresh Water Fish Comm., Nongame Wildl. Prog., Tallahassee, FL.

JONES, K. B. 1986. Amphibians and reptiles. Pp. 267–290. *In*: COOPERRIDER, A. Y., R. J. BOYD, AND H. R. STUART (eds.). Inventory and Monitoring of Wildlife Habitat. USDI Bur. Land Manage. Serv. Cent., Denver, CO.

KIESTER, A. R. 1971. Species density of North American amphibians and reptiles. Syst. Zool. 20:127–137.

LABISKY, R. F., J. A. HOVIS, R. W. REPENNING, AND D. J. WHITE. 1983. Wildlife inventory on the Apalachicola National Forest. Final report. USDA For. Serv. Coop. Agreement No. 19-340.

LACLAIRE, L. V. AND R. FRANZ. 1990. Importance of isolated wetlands in upland landscapes. Pp. 9–15. *In*: KELLY, M. (ed). Proc. Second Ann. Meet. Florida Lake Manage. Soc., Winter Haven, FL.

MEANS, D. B. 1992. One-toed amphiuma, *Amphiuma pholeter* Neill. Pp. 34–38. *In*: MOLER, P. E. (ed.). Rare and Endangered Biota of Florida. Volume III. Amphibians and Reptiles. Univ. Press Florida, Gainesville, FL.

——— AND D. SIMBERLOFF. 1987. The peninsula effect: habitat-correlated species declines in Florida's herpetofauna. J. Biogeogr. 14:551–568.

MOLER, P. E. AND R. FRANZ. 1987. Wildlife values of small, isolated wetlands in the southeastern coastal plain. Pp. 234–241. *In*: ODOM, R. R., K. A. RIDDLEBERGER, AND J. C. OZIER (eds.). Proc. Third S.E. Nongame and Endangered Wildl. Symp., Georgia Dept. Nat. Resour., Game and Fish Div., Social Circle, GA.

MONTAGUE, C. L. AND R. G. WIEGERT. 1990. Salt marshes. Pp. 481–516. *In*: MYERS, R. L. AND J. J. EWEL (eds.). Ecosystems of Florida. Univ. Central Florida Press, Orlando, FL.

MURPHY, C. G. 1993. A modified drift fence for capturing treefrogs. Herp. Rev. 24:143–145.

MUSHINSKY, H. R. 1985. Fire and the Florida sandhill herpetofaunal community: with special attention to responses of *Cnemidophorus sexlineatus*. Herpetologica 41:333–342.

——— AND E. D. MCCOY. 1995. Vertebrate species composition of selected scrub islands on the Lake Wales Ridge of central Florida. Florida Game and Fresh Water Fish Comm., Nongame Wildl. Prog. Proj. Rep., Tallahassee, FL.

NEILL, W. T. 1957. Historical biogeography of present-day Florida. Bull. Florida State Mus., Biol. Sci. 2:175–221.

———. 1958. The occurrence of amphibians and reptiles in saltwater areas, and a bibliography. Bull. Mar. Sci. Gulf Caribbean 8:1–97.

NOSS, R. F. 1988. The longleaf pine landscape of the Southeast: almost gone and almost forgotten. Univ. Michigan School Nat. Resour., Endangered Species Update 5(5):1–8.

PECHMANN, J. H. K., D. E. SCOTT, J. W. GIBBONS, AND R. D. SEMLITSCH. 1989. Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. Wetlands Ecol. Manage. 1:3–11.

PEET, R. K. 1993. A taxonomic study of *Aristida stricta* and *A. beyrichiana.* Rhodora 95:25–37.

TIMMERMAN, W. W., J. B. MILLER, AND C. V. TAMBORSKI. 1994. The herpetofauna of Jonathan Dickinson State Park, Martin County, Florida. Final Rept. Proj. No. 7618, Florida Dept. Environ. Prot., Div. Recreation and Parks, Hobe Sound, FL.

UMBER, R. W. AND L. D. HARRIS. 1974. Effects of intensive forestry on succession and wildlife in Florida sandhills. Proc. S.E. Assoc. Game and Fish Comm. Conf. 28:686–693.

U. S. FISH AND WILDLIFE SERVICE. 1978. Osceola National Forest phosphate extraction and processing: impacts on federally listed threatened or endangered and other species of concern. U.S. Fish Wildl. Serv., Natl. Fish Wildl. Lab., Gainesville, FL.

———. 1980. St. Marks National Wildlife Refuge: forestry management and non-game wildlife. Final Rept., U.S. Fish Wildl. Serv., Nat. Fish Wildl. Lab., Gainesville, FL.

VICKERS, C. R., L. D. HARRIS, AND B. F. SWINDEL. 1985. Changes in herpetofauna resulting from ditching of cypress ponds in coastal plains flatwoods. For. Ecol. Manage. 11:17–29.

WHITE, D. J. 1983. The herpetofaunal community of an abrupt forest edge in North Florida. M.S. Thesis, Univ. Florida, Gainesville, FL.

WILBUR, H. M. 1980. Complex life cycles. Ann. Rev. Ecol. Syst. 11:67–93.

WOOD, K. N. 1995. Geographic distribution: *Rhineura floridana* (Florida worm lizard). Herp. Rev. 26:44.

Florida Scient. 61(2): 61–87. 1998
Accepted: August 19, 1997

REMOVAL OF IRON FROM SODIUM FLUOROSILICATE SCALE BY MAGNETIC TREATMENT

Chuhua Wang, Robert F. Benson, and Dean F. Martin

Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, FL 33620-5050

Abstract: *Sodium fluorosilicate, a by-product of the production of phosphoric acid, is a nuisance material because of the tendency to build up in pipes and the need to remove the material from pipes. This material can be managed by application of magnetic fields (anti-scale magnetic treatment, AMT) The effect is ascribed to an increase in entropy as a result of the field, and the entropy increase results in an increase in the solubility of the scale. This present study addresses the effect of a magnetic field on iron impurities in the scale. In the presence of a magnetic field, there was a shift of iron concentration to smaller size particles. The phenomenon could be helpful in removing iron from the phosphoric acid stream or in providing purified sodium fluorosilicate.*

Excessive metallic impurities in phosphoric acid have caused economic and operating penalties on the industry. Removal of these unwanted metals would reduce post precipitation in the acid, reduce or eliminate scaling in the system, and make it possible to achieve a diammonium phosphate (DAP) grade of 18-46-0 without the addition of supplementary nitrogen (Lloyd, 1995). The nuisance metals include iron, aluminum, and magnesium.

A nuisance material, sodium fluorosilicate scale, is formed inside the walls of process pipes and containers in wet-process phosphoric acid through a reaction between phosphate ore and sulfuric acid. The build-up of sodium fluorosilicate scale reduces usable pipe volume and significantly affects heat transfer. The scale is partially soluble in water and phosphoric acid. Currently, a portion of the phosphoric acid plant must be shut down for the removal of the scale; and this is a nuisance and costly in terms of down time.

Antiscale magnetic treatment (AMT) has been reported as being effective in numerous instances (Baker and Judd, 1996; Benson et al., 1997). It removes existing scale or produces a softer and less tenacious scale in the instance of calcium carbonate. Large savings in energy, cleaning times and chemicals, and process downtime costs have been reported from the installation of magnetic water conditioners in real systems (Fryer, 1995; Baker and Judd, 1996; Benson et al., 1997).

Previously, we demonstrated the use of diamagnetism for enhancement of solubility of sodium fluorosilicate scale (Wang et al., 1998). In this paper, we demonstrate how a combination of diamagnetism and paramagnetism can alter the solubility of scale and serve to remove iron from the scale. We believe that magnetic treatment has two functions: one associated with conventional anti-scale magnetic treatment (Benson et al., 1998), and a second, purification of the scale by shifting the iron concentration to smaller-size particles, which could lead to a saleable product. And finally, association of iron with scale is a means of iron removal from phosphoric acid.

MATERIALS AND METHODS—*Materials*—Chunks of scale (May, 1995, weighing about 6.0 kg) from a phosphoric acid plant were provided by Mr. J. Harold Falls, Chief Chemist, CF Industries, Plant City, Florida. The samples consisted of layers of white and gray materials. The scale lumps were washed in water, then washed as clean as possible in distilled water, dried on paper towels, and allowed to air dry. Grinding was achieved as previously described and sieved into five portions (Wang et al., 1998).

A second sample of white scale (Dec., 1995) was separated and purified by removing the gray layer and polishing the white layer surface. White scale was used for the investigation of magnetic treatment on scale suspension.

Analysis of the scale was given previously, and the properties were consistent with sodium fluorosilicate contaminated with iron (Wang et al., 1998).

Iron analyses—Certain samples could not be measured reliably by atomic absorption spectrometry because of a high concentration of scale (saturated solutions), and the relative standard deviation was high at the 1 ppm iron level, so a thiocyanate colorimetric method (Marczenko, 1986) was used instead. A 2-g. sample of scale was digested with aqua regia ($3HCl:HNO_3$, v/v) and diluted to 100 mL at pH $=1 \pm 0.1$. These solutions were either measured directly or were measured after concentration by evaporation if the iron content was too low to be measured accurately. The measurable iron concentration for the thiocyanate method was 3–5 ppm. For those solutions of iron concentration less than 1 ppm, the concentration process was needed.

Magnetic treatment—Four methods were used. With *method a,* a 2-L reservoir was placed 8 m above the inlet of a hydrocyclone and the scale suspension was mechanically stirred. A PVC (1-in, 2.54 cm i.d.) pipe was used to connect reservoir and hydrocyclone, and the scale suspension was passed through the magnetic field 5 times (Fig. 1). Overflow solid and underflow solid were separated and were dried in a 75°C oven. The pH of the suspension solution was measured (Beckman Expandomatic® SS-2). Both samples of scale were investigated for the iron removal. With *method b* and *method c,* the reservoir was placed 1 m above inlet of the hydrocyclone and the scale suspension was magnetically stirred. Reservoir and hydrocyclone were connected by Tygon® tubing 3/8-in (9.5 mm) i.d. Two pairs of magnets (1200 gauss each) were placed on the outlet of the reservoir in *method b* and one magnetic set with 2-in i.d. pipe was applied in *method c.* The scale suspension was passed through the magnetic field once or 5 times. *Method d* was similar to the first, except a hydrocylcone was not used and the placement of the magnets differed (Fig. 2).

With all methods, the control and test experiments were done under the same conditions, except a magnetic field was not involved with the control experiments.

Wet sieving process—With *method d,* a wet sieving process was applied. Aqueous suspensions of scale were separated by sieves with mesh sizes of 18, 35, 60, 120, and 230. These correspond to openings of >1.0, 0.5, 0.25, 0.063, and <0.063 mm, respectively. The largest particles were first separated using the 18 mesh sieve, and collecting the suspension that passed though in a clean plastic bucket. The process was repeated using successively smaller sizes. The remainder of the suspension containing the finest particles was allowed to stand for five hours, when the suspension was collected by careful decanting. All five fractions were dried to constant weight in an oven at 75°C.

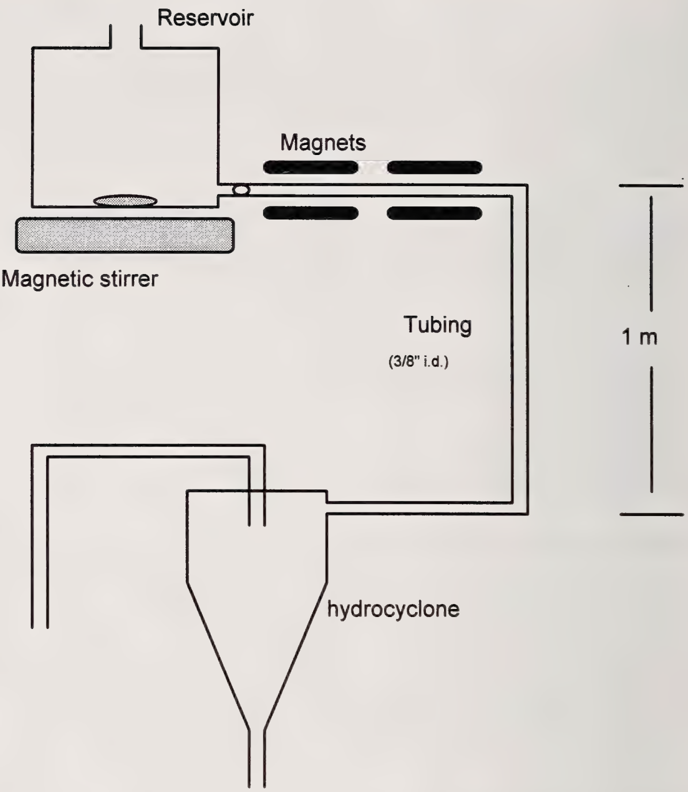


FIG. 1. Schematic representation of magnetic treatment using a hydrocyclone for separation.

Statistical analyses—The effect of treatments (magnetic field, test versus control samples) was assessed for statistical significance using ANOVA (analysis of variance, Havlicek and Crain, 1988). Two-way analysis of the variance proves the null hypothesis for row effects, which presumes that the means of two or more independent samples are not statistically significantly different. A probability, p, of less than 0.05 was taken as a criterion that the differences between two independent rows of data (typically size distributions) cannot be explained by random error alone. All ANOVA calculations were performed using PSI-PLOT software (Poly Software, 1992).

RESULTS AND DISCUSSION—*Characterization of scale*—Properties of the scale obtained from a phosphoric acid plant were summarized previously (Wang et al., 1998). Two samples, obtained at six-month intervals have similar fluoride content, and the analyses are consistent with sodium fluorosilicate with impurities of iron and other transition metals. The material crystallized as a mixture of white and gray crystals, which could be separated by hand. The gray material contained more iron and was paramagnetic: the white crystals contained considerably more fluoride, much less iron and was diamagnetic.

The observed magnetic susceptibilty for sodium fluorosilicate scale was $\chi_g = -0.31 \times 10^{-6}$ c.g.s. units (Table 1), whereas the reported value for

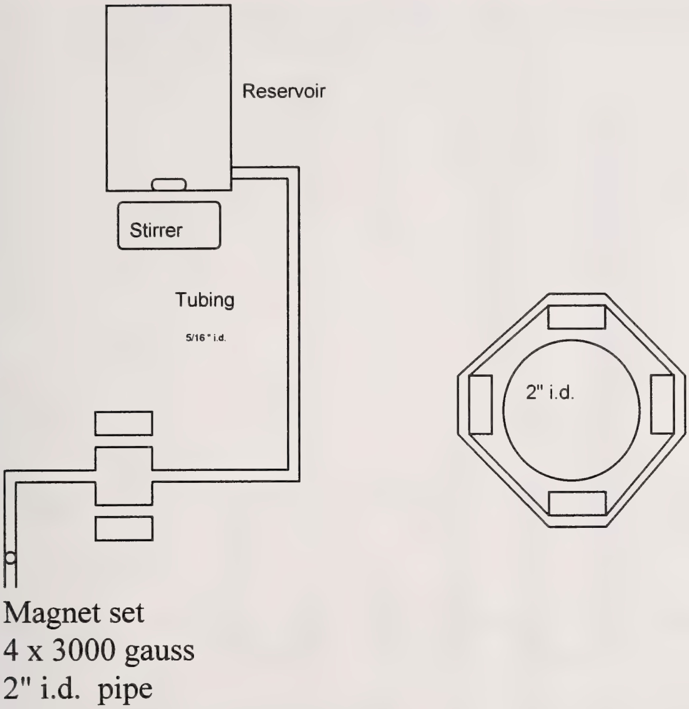


FIG. 2. Schematic arrangement of system for *method d* using a set of 4 × 3000 gauss magnets.

calcium carbonate is only slightly greater ($\chi_g = -0.382 \times 10^{-6}$ c.g.s.) (Weast, 1980). But both substances should be affected about the same in practice. One problem is the presence of iron, which reduces the effectiveness of diamagnetic treatment (cf. Table 1 in Benson et al., 1997).

Magnetic treatment—Experiments on magnetic treatment showed that there were changes in the distribution of iron in scale size fractions. This was true for all three hydroclone methods studied. A hydrocyclone was used

TABLE 1. Percent composition and magnetic susceptibilities for scale samples.

	------------ Percent Composition ------------				Magnetic susceptibility
Sample	Na	Si	F	Fe, ppm	10^6 (χ_g)
Na_2SiF_6 (theoretical)	24.5	14.9	60.6	—	
Sample 1 (5/105)	22.02	13.46	62.3 ± 1.3	47*	−0.31**
Sample 2 (12/105)					
white portion:			57.7 ± 1.4	30	−0.20
gray portion:			310.5 ± 1.3	1610	+0.0410

* White portion; ** Gram susceptibility, cgs units.

TABLE 2. Iron concentration in treated scale, underflow portion of hydrocyclone.*

Exp. No.	Scale Size (mm)	Iron, Test (ppm)	Iron, Control (ppm)	Difference** (%)
1, a	0.5–1.0	79.4	81.5	−2.58
2, a	0.25–0.50	115.1	161.7	−28.82
3, a	0.063–0.125	113.6	151.4	−24.97
4, a	<0.063	488	541	−9.80
5, b	0.5–1.0	22.7	25.2	−9.92
6, b	0.5–1.0	14.7	17.5	−16.00
7, b	0.063–0.125	20.7	26.7	−22.47
8, b, 1 cyc.	<0.063	33.3	36.6	−9.02
9, b	<0.063	38.3	45.6	−8.40
10, b	<0.063	48.6	47.7	+1.89
11, c	0.063–0.125	28.8	35.7	−19.33
12, c, 1 cyc.	0.063–0.125	37.4	45.6	−17.98
13, c	<0.063	39.2	40.7	−3.69
14, c	0.25–0.50	13.9	14.5	−4.14

* The treatment was 5 cycles in method a, b or c, and Difference (%) was ($\text{Iron}_{\text{test}} - \text{Iron}_{\text{control}})/\text{Iron}_{\text{control}}$.

** ANOVA: Treated vs. control. $p = 0.046$.

for separation into two fractions (Fig. 1): the upper (overflow) and the lower (underflow). The general trend was: a magnetic field resulted in a greater iron content in the overflow portion (solution and overflow solids) than with the control series (Martin et al., 1997). Less iron was found in the underflow portion for test samples (using a magnetic field) than for control samples (no magnetic field) (Table 2).

Two plausible explanations occur: artifact and entropy. We discount the former because we were careful to match the total amount of iron for the test and control samples (Fig. 3). The theoretical treatment of anti-scale magnetic treatment (AMT) that has been presented earlier suggests the effect of diamagnetic field is to increase the entropy of a system, and that this is manifested in an increase in the solubility of the affected species (Benson et al., 1994; Benson et al., 1997). With sodium fluorosilicate, for example, smaller particles would be more likely to dissolve in the presence of a magnetic field. Thus, the overflow solids after magnetic treatment were less than those for the control sample (Martin et al., 1997) while the underflow solid was not significantly different.

The situation is depicted (Fig. 3). Here, the right-hand bar indicates the similarity of iron content between test and control samples. The next bar to the left shows that the iron content of solution (1000 mL) had a greater iron content for the test sample than control. The other five bars represent the iron content of different size fractions, and the difference in iron content progressively increases with decreasing size of particles. This is summarized in Table 3, which also gives the mass balance for the system. Specifically, the total iron for initial, control, and test samples was similar (being 16.4, 16.0, and 16.3 mg, respectively).

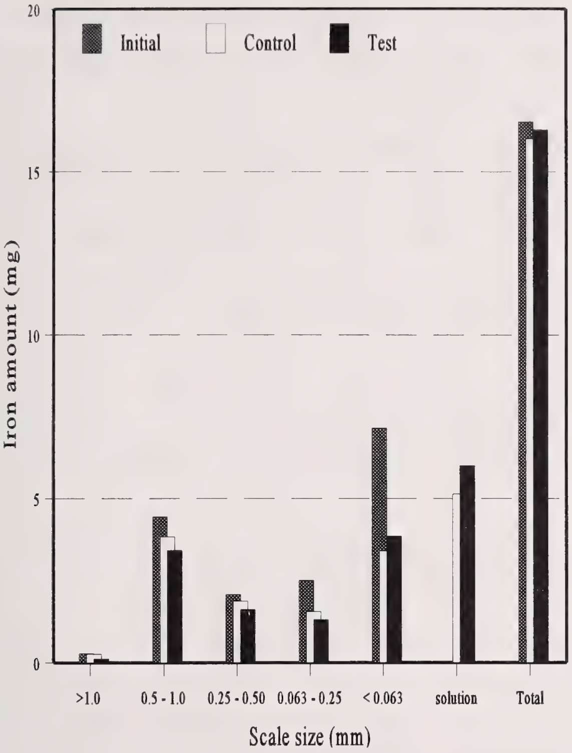


FIG. 3. Iron content of fluorosilicate scale as a function of particle size.

The scale solubility change and iron removal with the magnetic treatment show a similar trend. Probably iron species tend to coexist with smaller particles, and they are located at a interstitial position in Na_2SiF_6 lattice. When Na_2SiF_6 scale is dissolved, the iron species in scale goes into the liquid phase whether they are dissolved or not. Under the magnetic field treatment, more small particles were observed because of high entropy and less stable lattice, and those small particles are easily dissolved in solution because of their higher specific surface area. It is consistent that the scale shifts to smaller particles under the magnetic field.

The AMT process we have used, as we have noted (Benson, 1998) would not eliminate scale, but it would mitigate against its obvious inconvenience of formation in pipes. The effect persists for some period of time (so-called "memory effect") before equilibrium is restored (Reimers et al., 1992). Magnetic treatment would shift scale formation to an open area where it could be filtered off more conveniently and more economically.

In addition, we believe that scale can be used for two purposes: removal of iron from the phosphoric acid stream, where it is a recognized nuisance. And, we believe that it is possible to purify the fluorosilicate by a comparatively simple process of grinding, suspension in water, passage through a

TABLE 3. Iron content in sodium fluorosilicate scale after magnetic treatment Applied with a 2″ i.d. pipe and four magnets with a flow rate of 115 mL/sec*.

Scale Size (mm)	>1.0	0.5	0.25	0.063	<0.063	Solution	Total
Initial							
Weight (g)	5.00	40.00	20.00	20.00	15.00		100.0
Iron concn. (ppm)	54.7	111	103	125	478		
Iron amount (mg)	0.27	4.44	2.06	2.50	7.17		16.54
Control							
Weight (g)	4.71	35.70	21.31	15.54	6.63	1016	83.90
Iron concn. (ppm)	53.4	107	87.9	99.9	511	5.06	
Iron amount (mg)	0.25	3.82	1.87	1.55	3.39	5.13	16.01
Test							
Weight (g)	4.16	35.48	20.42	16.64	7.38	1016	84.08
Iron concn. (ppm)	29.5	96.2	79.0	78.0	520	5.91	
Iron amount (mg)	0.12	3.41	1.61	1.30	3.84	6.01	16.29
Difference in iron							
Fe, T − Fe, C (ppm)	−23.9	−10.3	−8.9	−21.9	9	0.85	
Fe, T − Fe, C (mg)	−0.13	−0.41	−0.26	−0.25	0.45	0.88	0.28
Fe, T − Fe, I (ppm)	−25.2	−14.8	−24.0	−47.0	42		
Fe, T − Fe, I (mg)	−0.15	−1.03	−0.45	−1.2	−3.33	6.01	−0.25
Fe, C − Fe, I (ppm)	−1.3	−4.0	−15.1	−25.1	33		
Fe, C − Fe, I (mg)	−0.02	−0.62	−0.19	−0.95	−3.78	5.13	−0.53

* T—Test, C − Control, I—Initial.

magnetic field and separation with hydrocyclones. The major question, of course, is whether the phosphate industry would wish to purify scale for sale in competition with other sources. The long-term answer to many questions, that "circumstances alter cases", likely applies here as well.

We believe that these experiments form a sound theoretical and practical basis for future efforts to manage scale in phosphoric acid plants. This could be achieved through the judicious placement of suitable magnets so that scale instead of forming in inconvenient locations (pipes, especially bent pipes and on filter cloth) would be transported to a more convenient location for separation. In addition, magnetic treatment schemes studied here have implications for removing iron through association with fluorosilicate scale.

ACKNOWLEDGMENTS—We are grateful for the financial assistance of the Florida Institute of Phosphate Research through contract #94-01-116, and we appreciate the helpful comments of G. Michael Lloyd, Jr. We appreciate the loan of magnets by Roland K. Carpenter, President, AquaMagnetics® International, Inc. Barbara B. Martin served as Consulting Editor.

LITERATURE CITED

BAKER, J. S. AND S. J. JUDD. 1996. Magnetic amelioration of scale formation. Water Res. 30: 247–260.

BENSON, R. F., B. B. MARTIN, D. F. MARTIN, AND R. K. CARPENTER. 1994. Management of scale deposits by diamagnetism. A working hypothesis. J. Environ. Sci. Health A29:1554–1564.

———, R. K. CARPENTER, B. B. MARTIN, AND D. F. MARTIN. 1997. Using magnetic fields to prevent scale. Chemtech 27(4):34–39.

———, J. C. DAVIS, JR., AND D. F. MARTIN. 1998. Magnetic effects on solubility . Unpublished manuscript.

FRYER, L. 1995. Magnetic Water Treatment. A Coming Attraction? Tech. Update TU-95-7. E Source Reprints Service, 1033 Walnut Street, Boulder, Colorado. 21 pp.

HAVLICEK, I. AND R. CRAIN. 1988. Practical Statistics for the Physical Sciences. American Chemical Society, Washington, D.C.

LLOYD, G. M., JR. 1995. Report to the Board of Directors, Florida Institute of Phosphate Research, Bartow, FL.

MARCZENKO, Z. 1986. Separation and Spectrophotometric Determination of Elements. Halstead Press, New York, NY.

MARTIN, D. F., R. F. BENSON, E. PÉREZ, B. B. MARTIN, C. WANG, M. GALLARDO, AND M. DERBY. 1997. Removal of Unwanted Metals and Materials in Phosphoric Acid by Means of Magnetic Separation. Final Report FIPR #94-01-116. Florida Institute of Phosphate Research. Bartow, FL.

POLYSOFTWARE. 1992. PSI-PLOT. Polysoftware International, Ltd. Salt Lake City, UT.

REIMERS, R. R., M. SHARIAT, R. K. CARPENTER, AND T. G. AKERS. 1992. The role of chemical constituents and their effects on scale inhibition following magnetic treatment. Report from the Department of Environmental Health Sciences, School of Public Health and Tropical Medicine, Tulane University, New Orleans, LA.

WANG, C., R. F. BENSON, AND D. F. MARTIN. 1998. Enhanced solubility of sodium fluorosilicate scale by magnetic treatment. Florida Scient. 61(1):17–25.

WEAST, R. C. 1980. CRC Handbook of Chemistry and Physics. CRC Press, Boca Raton, FL, p. E-125.

Florida Scient. 61(2): 88–95. 1998
Accepted: August 29, 1997

FLORIDA AND GLOBAL WARMING

JAY W. PALMER

Institute of Environmental Studies, Department of Chemistry, University of South Florida,
4202 E. Fowler Ave., Tampa FL 33620–5150

ABSTRACT: *If current global warming projections are accurate, Florida's climate will be altered significantly. Fifty years from now, Florida will be hotter, wetter, and have more flooding, more hurricanes, and more tropical diseases. A proposal has been made that may reduce the rate of global warming.*

NO issue of our times is more controversial than that global warming is caused by greenhouse gases. Newspaper headlines may read on one day, "Global Warming is Real," and on another backlash headlines such as, "Greenhouse Effect May Be Hot Air" (Gates, 1993). What is the truth? In order to predict Florida's climate, we must know past global climate and understand factors that cause climate change. This review enables us to create a scenario for Florida's past climate and a prediction for its future climate.

PAST GLOBAL CLIMATES—Patrick Henry is quoted as saying, "I know of no way of judging the future but by the past."

The history of the earth is filled with catastrophes of extinctions of varying degrees (Benton, 1995). The one that has captured our imagination is the extinction of dinosaurs 65 million years ago which destroyed half of all species. As severe as this one was, it pales in comparison to the disaster which occurred around 250 million years ago—a mass extinction of about 90% of all species in the oceans, more than two-thirds of reptile and amphibian families on land, and 30% of the insect orders. This is the only known assault on insect orders.

There is no shortage of murder suspects for these catastrophes: oxidation and burial of carbon, considerable lowering of the sea level with possible anoxia, and extensive volcanism—all occurring in less that a million years (Erwin, 1996). This suggests a complex mechanism for extinction in which major climatic changes occur including extensive glaciation with long-term ice ages. Fortunately, we are now able to simulate climates through computer modeling to better understand the complexity of change.

From 100 to 65 million years ago, the earth was more than 20 degrees Celsius warmer than today. No ice caps were present. About 55 million years ago the global climate began a long, slow, cooling trend culminating in extensive glaciation. This glaciation, our present "glacial" age, is believed to be only the third widespread continental glaciation ever to occur on earth (Gates, 1993).

A review of the last 17,000 years beginning with the last maximum glacial expansion, shows that in the northern hemisphere there were four major global warming and four major global cooling periods if the "Little Ice Age" beginning about AD 1430 is included. In addition, there were numerous small, localized variations in climatic temperature (Lamb, 1995).

The first global warming period was the most intensive, reaching a maximum about 8500 years ago resulting in a climate not nearly as warm as today but one in which the ocean levels had risen 115 meters (Fairbridge, 1961). Agriculture developed throughout the world. Then a cooling period began with neo-glacial advances that lasted a little over 1000 years before reversal with a new global warming period. This second global warming reached a maximum around 6000 years ago which was considerably warmer than today (Gates, 1993). The oceans rose another 15 meters from the previous high to a new level greater than two meters higher than today (Fairbridge, 1961).

This hot climate lasted over 1000 years resulting in a very dry broad band around the northern hemisphere. In the Near East complete cities were abandoned (Issar, 1995). Great Basin lakes in intermountain North America dried up. One, Lake Bonneville, which had been almost as large as Lake Michigan with an outlet into the Columbia River 14,000 years ago, now was dry—not even a small lake left where Great Salt Lake is today (Barry, 1983). Another cooling period with neo-glacial advances followed and lasted about 1000 years.

Then a third global warming occurred reaching a maximum around 4000 years ago (Isaar, 1995), and the climate became much warmer than today. The Great Plains and Midwest regions of North America became very dry; however, the western region of Greenland became green with grass for large herds of caribou. It was so inviting that a number of Asiatic groups from Siberia colonized it via Alaska and northern Canada (Palmer, 1997). Global warming was then so extensive that the Near East became a desert with abandoned cities, and the level of the Red Sea dropped 100 meters. However, the Arabian peninsula and the Saharan region of North Africa were inundated by monsoon rains which resulted in grassy savannas and flowing rivers (Lamb, 1995).

About 3300 years ago, a third global cooling began with neo-glacial advances. Forests in Canada moved well south of the regions they had reached during previous global warming (Gates, 1993). The extensive grasslands of Greenland with their herds of caribou disappeared forcing Proto-Dorset people to migrate to the Canadian mainland (Palmer, 1997). Farming people in northern Scandinavia moved south thus initiating the great Germanic invasions of Europe. It also was a time of many earthquakes and volcanic eruptions—one being the enormous eruption of Santorin on the island of Thira in the Aegean (Lamb, 1995).

A fourth period of global warming began around AD 500. The Middle East became very dry (Issar, 1995) and Arabia and northern Africa became deserts. England became so warm that many vineyards and wineries were established (Lamb, 1995). Proto-Dorset people and caribou herds moved back into Greenland. By AD 1000 the narrow straits between Canada and Greenland as well as parts of the Arctic Ocean had become free of ice allowing migrating Thule Eskimos to harvest whales. Green pastures in Greenland welcomed colonization by Icelandic Norse (Palmer, 1997). Southwestern North America had become lush from monsoon rains, and extensive farming was practiced in the midwest.

However, by AD 1300 severe global warming caused the northern part of the Southwest, the Great Basin, the Great Plains, and the midwest to become so dry that residents were forced to move to wetter regions in the north and east (Palmer, 1994).

Around AD 1430, a fourth period of global cooling began. Greenland Norse abandoned their colonies, the Dorset disappeared, and many Thule Eskimo left Greenland for Canada and Alaska (Palmer, 1997). The Thames River in London froze during winters and many vineyards in England died. The Little Ice Age was in full swing (Lamb, 1995).

A good correlation exists among increasing volcanic activity, increasing glacial ice, and a colder climate in Iceland and the northern hemisphere (Lamb, 1995). Benjamin Franklin noted that volcanic aerosols reflect sunlight and suggested that the eruption of the large volcano in Iceland caused the unusual cold and haze of 1783–1784 in Europe (Gates, 1993). The largest volcanic eruption during this time was in April 1815 of Mt. Tambora in Sumbawa, Indonesia. In America and Europe, 1816 became known as "the year without a summer." Convincing analyses show that the ash and sulfur oxides probably caused the global temperature reductions (Strothers, 1984); however, there is still considerable controversy.

The end of the Little Ice Age is generally given as around 1850 when a warming trend began (Gates, 1993). But, there were times when a cooling period took place such as in 1982 when El Chinchon erupted. The El Chinchon cooling effect was almost over in 1991 when Mt. Pinatubo erupted (Parsons, 1995). The question now arises: Are volcanic eruptions the only reason for cyclic cooling and warming of climates? For an answer, we must go to the causes of climatic change.

GLOBAL CLIMATIC CHANGE—The amount of heat input to the earth from the sun is dependent to some degree upon the sun's surface activity (sun spots) which also affects the frequency of radiation on the ultraviolet end of the spectrum. Since the earth moves in an elliptical orbit around the sun, there is a seasonal variation. However, the shape of this orbit changes over time to a more circular orbit by the pull on the earth from other planets.

This measure of ellipticity is called eccentricity and has a periodicity of about 100,000 years. The axis of the earth is tilted. This obliquity varies with a periodicity of 41,000 years. In addition, the north magnetic pole wanders with a periodicity of 22,000 years. Stellar dust and terrestrial magnetism play a minor role. All of these factors contribute to heat input variation (Gates, 1993).

The total amount of heat reaching the earth's surface will depend upon the quality of the earth's atmosphere. Quality is affected by dust particles (volcanic, wind-blown, and burning fossil fuels), greenhouse gases (in decreasing importance: water vapor, carbon dioxide, methane, sulfur oxides, nitrogen oxides, ozone, other gases that influence the concentration of greenhouse gases), and cloud cover. Some radiation will be reflected back into space. The albedo of lands mass and oceans depends upon sea ice cover, snow cover, ice cap extent, vegetation, dust on snow etc. This penetrating heat input is coupled with some heat generated through fossil fuel burning (Wuebbles, 1995).

Distribution and altitude of land masses and oceans are influenced by mountain building, polar wandering, sea-floor spreading, latitudinal shifts, changes in sill depths, changes in channel widths and sea level. These in turn influence ocean currents, build-up and decay of ice caps, albedo of land mass and oceans. All influence climate. However, for relatively short-term global warming and cooling, sun spots, atmospheric dust, greenhouse gases, cloud cover, and feed-back from global warming or cooling probably are most important (Gates, 1993).

Though water is the principal component of every aspect of global climate, water is the least documented or understood feature of global climate. Its role in global warming and cooling is complex. Water is ubiquitous, and it is the only substance that exists naturally in three phases: solid, liquid, and gas (vapor). Ice and snow are very efficient at reflecting the sun's radiation back into space. Liquid water in clouds reflects and absorbs the sun's radiation, and reflects, absorbs, and re-emits the earth's radiation. On an average day, clouds cover over 60% of the earth's surface. As the unimolecular species, water vapor, is transparent to almost all the sun's radiation yet it absorbs the earth's radiation, thus functioning as a greenhouse gas that is much more effective (60–70% of the total greenhouse effect) than all of the other greenhouse gases (Parsons, 1995).

Of special interest is the infrared (IR) region between the wavelengths of 4 μm and 100 μm where the earth re-emits much of its absorbed energy back into space (Table 1). Although water vapor, carbon dioxide, and other greenhouse gases are relatively weak absorbers of solar radiation, they are strong absorbers of IR radiation. Liquid water contained in clouds has vibration-rotational bands which absorb most radiation at wavelengths less than 6.5 μm, and has rotational bands which absorb most radiation at wavelengths greater than 11 μm. Greenhouse gases (and clouds) re-emit their absorbed energy in all directions, and most is lost to space. Some, though,

TABLE 1. Some infrared spectral bands of liquid water and greenhouse gases.

Compound	Vibration-rotational bands			Rotational bands	
Liquid water	2.5 to 3.6 µm	4 to 5.3 µm	5.6 to 6.5 µm	greater than 11 µm	
Water vapor	2.7 µm	5 to 7.7 µm			
Carbon dioxide	2.5 µm	3 µm		11 to 15 µm	
Methane	3 µm			9 µm	
Nitrous oxide	4 µm			8 µm	18 µm
Ozone	0.6 µm			9.5 µm	14 µm
$CFCl_3$ and CF_2Cl_2				11 µm	

is re-emitted downward leading to warming of the earth's surface (Parsons, 1995).

Regions between 2 µm and 2.5 µm, 3.5 µm and 4 µm, 6.5 µm and 12 µm, are windows that permit heat from the surface of the earth to pass directly into space. The spectral region from about 8 to 12 µm is referred to as the "window" where nearly 80% of the radiation emitted by the surface escapes. However, water vapor absorbs strongly between 5 µm and 8 µm, carbon dioxide at 2.5 µm, 3.0 µm and between 11 µm and 15 µm, methane at 9 µm and nitrous oxide, ozone and the fluoro-chloro-carbons between 8 µm and 18 µm (Wuebbles, 1995). Thus, increased presence of these gases reduces the amount of heat lost directly to space, while reduction of these gases increases the amount of heat lost to space.

While most of the U.S. has experienced increased precipitation over the past century, some areas are considerably drier. Increases in precipitation and drought are inevitable in a warmer world. This world has higher temperatures and greater water evaporation rates. As a result, there is more moisture in the atmosphere to be rained out. Inevitably, when it doesn't rain for a while, land areas dry out faster and drought is more severe (Hileman, 1997). Playing a role is the percentage of moisture in the atmosphere present as the greenhouse gas (water vapor), submicron liquid water aerosols, and the number of these aerosols that grow large enough to precipitate as rain or snow.

Water molecules (water vapor) can coat small dust particles, combine with sulfur oxides and nitrogen oxides, or combine with itself through hydrogen bonding to form aerosol particles that screen and reflect the sun's radiant energy. All these particles can act as nuclei upon which more water molecules can condense forming submicron water droplets which aggregate into clouds. These droplets can grow in size until they fall as rain, thus cleansing the atmosphere (Pueschel, 1995).

Oceans absorb the sun's radiation and act as a tremendous heat sink that resists temperature change. Considering these manifestations, if it were not for the global warming effect of water vapor and liquid water contained in clouds, our planet would be 30°C cooler (Parsons, 1995).

Slow cooling leading to glaciation is influenced considerably by volcanic ash, sulfur oxides, and water vapor. These particulates and gases combine with water molecules in the atmosphere to give hydrated ash and sulfuric acid aerosols that reflect solar energy. The higher the particulates are blown into the atmosphere the greater the reflection. Those that reach the stratosphere will remain suspended for years since the amount of water vapor for combination will be small. As the earth becomes colder much of its surface becomes desert from which soil particulates can be blown into the atmosphere, but settle out quickly (Pueschel, 1995).

The Little Ice Age was more intense in the northern hemisphere especially in North America and Europe. This correlates well with volcanic activity in Iceland except after 1850 when volcanism decreased in Iceland and throughout the world. From 1850 to 1975, even with decreased volcanism, climate in the northern hemisphere remained cool—the temperature from 1940 to 1975 actually decreased (Gates, 1993). Since this was a time of increased industrial activity—coal burning, mineral sulfide smelting, and sulfuric acid production—fly ash and sulfur oxide emissions may have been significant in keeping the northern hemisphere cool (Wuebbles, 1995). "Pollutant haze cools the greenhouse" (Kerr, 1992). Clean-air acts in the mid 70's drastically reduced these emissions which corresponds to the spurt in global warming. There were two sudden drops in temperature corresponding to El Chichón volcanic eruption in 1982 and the Mt. Penatubo volcanic eruption in 1992 (Parsons, 1995).

As waters cool during glaciation more carbon dioxide is dissolved forming clathrates. Methane also forms clathrates in wet lands, oceans and aquifers. These changes will enhance the cooling process (Parsons, 1995). Conversely, both of these gases will be released from water bodies during global warming.

A comparison of atmospheric dust levels and greenhouse gases trapped in glacial ice with present day levels is revealing. Tropical atmospheric dust-levels at the last glacial maximum (17,000 years ago) were about 200 times greater than today (Thompson et al., 1995). Carbon dioxide (CO_2) was 190–200 ppm compared with 355 ppm today, and methane has increased from 350 ppb to 1700 ppb (Gates, 1993) or 700 ppb (Brooke et al., 1996). Mean global warming during this last deglaciation is estimated as 4.5°C. of which 2.3°C. may come from the climate forcing of these two greenhouse gases (Gates, 1993). However, the extent of global warming resulting from increased water vapor apparently has not been estimated but could be considerable with the remaining global warming coming from reduced dust levels.

Increased carbon dioxide content in the atmosphere will promote the growth of plant life which in turn will remove carbon dioxide from the atmosphere. With the fixation of carbon in plant life, more methane can be released from both plants and animals which promotes global warming. Anthromorphic burning of coal and methane or atmospheric oxidation of organic matter in exposed soil surfaces during tilling releases more carbon dioxide and water vapor. These factors add complexity to global warming and cooling.

Both global heating and cooling influence atmospheric and oceanic circulation patterns which may be part of "Chaotic Climate." Models (Broecker, 1995) suggest that circulation of heat and salt through the oceans can change suddenly, causing drastic effects on global climate. Giant circulation cells cover the length of each ocean. In the Atlantic, warm upper waters flow northward to Greenland, are cooled by polar air, become heavier, and sink forming a lower current that flows towards Antarctica. There, being warmer and less dense than the surface water, it wells up, is cooled, and sinks. Tongues of this cold bottom water flow north into the Atlantic, Pacific, and Indian Oceans welling up again and again (Broecker, 1995).

Mountains around the Atlantic Basin cause more ocean water to evaporate giving higher salt concentration and denser water. Descent of heavier water in the northern region begins a global pattern to redistribute the excess salt throughout the oceans. This circulation results in an enormous northward transport of heat causing the warm climate of Europe (Broecker, 1995).

This pattern may be disrupted by injections of fresh Arctic water into the North Atlantic which can shut down the circulation system. When this happens, winter temperatures in the North Atlantic may drop as much as five or more degrees Celsius. Conceivably, Dublin could acquire the climate of Spitsbergen almost 1,000 kilometers north of the Arctic Circle (Broecker, 1995).

Changed circulation patters in the North Atlantic could alter the amount of cold water welling to the surface along the equator in the Pacific. Reduction of equatorial upwelling, as is occurring now during the El Niño period, can cause extensive droughts in some areas and floods in others (Broecker, 1995). Cold upwelling now taking place in the northern Atlantic and northern Pacific regions may be responsible for present and future hard winters and heavy floods in Europe and America.

A recent review (Karl et al., 1997) states that the consensus of the experts is that: the global average temperature has increased and will continue to increase; precipitation has increased and will continue to increase; and the weather has become more violent and will continue to become more violent.

Past Florida Climate—Based on this background, what can be said about the climate of Florida? During much of the last Ice Age through the last glacial maximum to about 10,000 years ago, Florida likely was a desert covered with silica-sand dunes. The ocean level during the first part of this time was some 120 meters lower than today (Schneider, 1997). Probably Florida was not populated by any large animals.

From 10,000 to 9,000 years ago Florida's land mass decreased considerably as the ocean level rose over 115 meters. The climate became warmer but was still colder than at present with more rainfall. Increased foliage and mastodons appeared. The climate between 9,000 and 6,000 years ago was characterized by wide swings in weather and sea level.

However, by 6,000 years ago Florida had become much warmer, sea level was several meters higher than at present, and mastodons had disappeared. Following an intermediate cooling period, another global maximum was reached about 4,000 years ago. The cycle continued with a minimum cooling period about 2,000 years ago, a warming period between AD 500 and AD 1400, then a cooling period causing the Little Ice Age. With the exception of the global warming period climaxing at 9,000 years ago, all global warming maxima were warmer than today and all global cooling minima were cooler than today. Evidence is strong that our current global warming began about AD 1850 and could reach a maximum comparable to these latter global warming maxima.

Conclusions—So with a gradual warming trend taking place, what happens in Florida during the next 50 years? At present, the amount of water vapor in the atmosphere over Florida is about the same as over the past 100 years, while that over most of the rest of the United States is 10 to 20% higher than a century ago (Hileman, 1997). However, as the climate becomes warmer, rainfall will increase. With warmer summer days there will be more thunderstorms and more violent thunderstorms with more tornadoes.

It is difficult to predict the number of hurricanes that will hit Florida. The increasing presence of El Niño usually means fewer hurricanes. However, increased global warming means more hurricanes coming ashore on Florida's east coast and fewer on the west coast. With increased melting of polar ice packs, Florida's sea level may rise half a meter higher causing more flooding especially during summer tropical storms. Even half a meter could cause much of the present beach area to disappear.

With atmospheric circulation patterns moving northward along the west coast of North America, more fronts will develop off the coasts of Washington and Oregon. As these fronts more eastward they merge with fronts moving southeastward from the Arctic to form more powerful fronts that can bring more rain and freezing weather to Florida. Other Florida winters may have less rainfall depending upon the relative strengths of the two frontal systems. More intensive fronts carrying much moisture from the Northwest and less intensive polar fronts will allow storms to dump heavy rain and snow across the upper United States with very little reaching Florida.

A warmer, more humid monsoon summer climate in Florida will provide favorable conditions for tropical diseases such as malaria (already two cases have occurred in 1997 with only one in history before), dengue, schistosomiasis, and all five strains of hepatitis; other new diseases such as the ebo virus may become widespread.

Florida has been called a desert with lots of water. This concept can be extended to the lack of nutrients in its silica-sand soil. The silica-sand of

Florida does not retain nutrients, yet 24–26 elemental nutrients are needed by the plant world. Nutrients can fall with rain, but they need to come from somewhere else—western dust storms, particulate emissions from volcanoes, industrial factories or motor vehicles. Increased rainfall will wash more of these nutrients into the lakes, rivers, and oceans aggravating the shortage.

What are our alternatives? Must we resign ourselves to floods, famine, and disease? Current thinking is focused on the removal of carbon dioxides, sulfur oxides and nitrogen oxides (greenhouse pollutants) from the atmosphere. A compromise is needed. Mankind in the past has stalled global warming unknowingly, which may offer us at least a partial solution. Burning of sulfur and clay containing coal without scrubbers in industrial plants provides aerosol nuclei for condensation of the most powerful greenhouse gas, water vapor, into energy-reflecting water-droplet clouds (Kerr, 1995). When these droplets fall as rain they bring plant nutrients to our barren soils, thus, promoting plant life which removes the greenhouse gases, carbon dioxide, sulfur oxides, and nitrogen oxides, from our atmosphere.

We can capitalize on this observation by generating seed nuclei containing all 26 elemental plant nutrients by mixing their acid and basic solution in ground or aircraft generators much as was done with silver iodide cloud seeding in rain making. These nuclei would provide seed for condensation of water vapor into energy-reflecting sub-micron water-droplet clouds. When water droplets grow into raindrops, falling rain can fertilize barren silica-sand areas of Florida. For those areas that have silaceous-carbonate soils, more acidic nuclei can be used to liberate additional vital nutrients. Increased plant life will remove additional carbon dioxide from the atmosphere. The major greenhouse gases, water vapor and carbon dioxide, will decrease, which coupled with more energy-reflecting clouds, will curtail global warming.

Before we as a nation sign any agreements that may profoundly influence our future life, other plausible alternatives to curtain global warming should be investigated.

LITERATURE CITED

BARRY, R. G. 1983. Late-pleistocene climatology. Pp. 390–405. *In*: WRIGHT, H. E. JR. (ed.). Late Quaternary Environments of the United States. PORTER, S. C. (ed.). The Late Pleistocene, v. 1. Longman, London.

BENTON, M. J. 1995. Diversification and extinction in the history of life. Science 268:52–58.

BROECKER, W. S. 1995. Chaotic climate. Scien. Amer. 273(5):62–68.

BROOKE, E. J., T. SOWERS, AND J. ORCHARD. 1996. Rapid variations in atmospheric methane concentration during the past 110,000 years. Science 273:1087–1091.

ERWIN, D. H. 1996. The mother of mass extinctions. Scien. Amer. 275(1):72–78.

FAIRBRIDGE, R. W. 1961. Eustatic changes in sea level. Pp. 99–185. *In*: AHRENS, L. H., F. PRESS, K. RANKAMA, AND S. K. RUNCORN (eds.). Physics and Chemistry of the Earth. v. 4. Pergamon Press, New York.

GATES, D. M. 1993. Climate Change and its Biological Consequences. Sinauer Associates, Inc., Sunderland, MS, 280 pp.

HILEMAN, B. 1997. Storm warnings rattle insurers. Chem. Engn. News. April 14, pp. 28–31.

ISSAR, A. S. 1995. Climatic change and the history of the Middle East. Amer. Science 83:350–355.

KARL, T. R., N. NICHOLLS, AND J. GREGORY. 1997. The coming climate. Scien. Amer. 276(5): 78–83.

KERR, R. A. 1992. Pollutant haze cools the green house. Science 255:682–683.

———. 1995. Study unveils climate cooling caused by pollutant haze. Science 268:802.

LAMB, H. H. 1995. Climate, History and the Modern World. Routledge, New York, 433 pp.

PALMER, J. W. 1994. The prehistoric migrations of the Cherokee. North Am. Archaeol. 15: 31–52.

———. 1997. The Dorset: an enigma. North Am. Archaeol. In press.

PARSONS, M. L. 1995. Global Warming: The Truth behind the Myth, Plenum Press, New York, 414 pp.

PUESCHEL, R. F. 1995. Atmospheric aerosols. Pp. 121–175. *In*: SINGH, HANWAT B. (ed.). Composition, Chemistry, and Climate of the Atmosphere. Van Nostrand Reinhold, New York.

SCHNEIDER, D. 1997. The rising seas. Scien. Amer. 276(3):112–117.

STROTHERS, R. B. 1984. The great Tambora eruption in 1815 and its aftermath. Science 234: 1191–1198.

THOMPSON, L. G., E. MOSLEY-THOMPSON, M. E. DAVIS, P.-N. LIN, K. A. HENDERSON, J. COLE-DAI, J. F. BOLZAN, AND K.-B. LIU. 1995. Late glacial stage and holocene tropical ice core records from Huascaran, Peru. Science 269:46–50.

WUEBBLES, D. J. 1995. Air pollution and climatic change. Pp. 480–518. *In*: SINGH, H. B. (ed.). Composition, Chemistry, and Climate of the Atmosphere. van Nostrand Reinhold, New York.

Florida Scient. 61(2): 96–105. 1998
Accepted: September 10, 1997

INVASIVE EXOTIC CLIMBERS IN FLORIDA: BIOGEOGRAPHY, ECOLOGY, AND PROBLEMS

Daniel F. Austin

Department of Biological Sciences, Florida Atlantic University, Boca Raton, FL 33431

Abstract: *The Florida Exotic Pest Plant Council (EPPC) has been publishing a list of invasive plants in the state since 1991. The 1997 list includes 29 species with the climber life-form. A historical summary of the introduction of these species, and the place of the life-form in the ecology of North America is presented. The conclusion is drawn that this life strategy is less common in North America than in the tropics. That factor, plus several not examined, has contributed to many species of climbers becoming invasive pests in native Florida plant communities.*

Beginning in 1991, the Florida Exotic Pest Plant Council (EPPC) produced lists of "Invasive" exotic or alien species for the state (cf. EPPC, 1995, 1997). The species on these lists have generated a controversy between managers of natural areas and other interests. Often, the biology of the organisms has been lost in the political arena. The following discussion supplies data on one subset of invasive alien Florida plants.

The 1997 EPPC list includes 29 species of climbers (also called vines, twiners, creepers, lianas, and other names in English, cf. Austin, 1994). Humans have introduced into Florida dozens of species with this life-strategy. Many species have escaped into disturbed and wild sites; only those invading native intact communities have been included in the EPPC list. Because climbers flourish first in the natural gaps that form in all communities, these openings in Florida habitats are more likely to be colonized by non-native species. These alien species have few or none of the controlling organisms that inhibit our natives. The result is a dramatic alteration of normal successional sequences. Habitat managers face the problem of how to handle these situations.

There seem to be two options for handling the problem: (1) allow succession to proceed un-managed; and (2) attempt some management. While one could make biogeographic and economic arguments for the former approach, few managers would find these philosophic and academic ideas acceptable. Regardless of approach, the fact is that invasion by all life-forms of alien species lowers biodiversity. Those in charge of preserved habitats constantly seek solutions through management. No management answers are given here. Instead, the following is an introduction to the ecology of vines, and to the more prevalent invaders in what has become a war to sustain native plant biodiversity.

BIOGEOGRAPHY AND ECOLOGY—Ecologically all climbers in North America are gap-invaders; many are pioneer species. Recent ecological studies on vines show that they are associated with gaps in forests (Putz, 1984; Collins and Wein, 1993), topographic location (Putz and Chai, 1987), streams (Lott et al., 1987; Molina-Freaner and Tinoco-Ojanguren, 1997), and trellis availability (Balfour and Bond, 1993; Molina-Freaner and Tinoco-Ojanguren, 1997).

A comparison of some North American vine floras provides instructive data (Table 1, Fig. 1). When these data are compared with the same life-form in Barro Colorado Island, Panama, trends are more obvious (Putz, 1984). Floras in Kentucky, Georgia, and the Florida Panhandle contain from 93 to 126 species of native climbers. Southern Florida is about the same with 101 species. The figure jumps to 481 species in Cuba. Barro Colorado Island, Panama, is only 6 square miles or 15.6 km^2 yet it has 265 vines out of 1369 species (Croat, 1978), or 20.1% of the flora (Table 1). Climber increase within the tropics indicates that continental North America has an impoverished flora in this life-form (Fig. 1). Within each of the North American sample areas there are many exotic climbers that have been introduced, rising to 33% of the life-form in southern Florida. Presumably these invasive species have been able to become established in North America because the temperate regions have impoverished floras, and the exotic populations are not controlled by herbivores and pathogens from their native areas.

Alien plants are not the only ones causing what we perceive as problems. Alteration of the water and fire regimes (i.e., disturbance) in Florida have produced an equal problem with *Vitis* and lesser difficulties with other native climbers. Nonetheless, the exotic species are more vigorous and typically cover other plants faster than natives.

THE SPECIES—Plants discussed below are taken from the 1997 Exotic Pest Plant Council "Invasive" list (EPPC, 1997), and from the EPPC database (DEP, 1997). Localities documented by herbarium specimens are given by Wunderlin and co-workers (1996). Most of the climbers, and other species on the EPPC list, were introduced for focused, single-purpose, human-related reasons. No regard was given for the biology of the plants, their invasive potential, or ecological attributes. Subsequently, these species escaped from cultivation and began invading native lands. Once established in Florida habitats, these alien organisms began competing with local plants and those listed here have more successful life strategies than many natives. Especially compromised are endangered Florida plants; these are declining rapidly in part because of the exotics.

Most of the introduction dates for these species are conservative (Table 2). R. Pemberton (1997) has recently discovered that the Reasoner's "Royal Palm Nurseries," of Oneco, Manatee Co., that flourished between 1887 and 1930, offered many non-native plants for sale in Florida. He is preparing a list of the species in their catalogues that will be published soon.

ROSARY PEA (*Abrus precatorius*: Fabaceae)—Native to the Old World tropics, these vines occur nearly throughout the peninsula (Wunderlin, 1982; Wunderlin et al., 1996). This vine was first offered for sale by the "Royal Palm Nurseries" in 1887–88 (R. Pemberton, 1997). Simpson (1916) commented that, ". . .when once established on a place it spreads rapidly by means of its seeds." Birds spread the red and black seeds.

CORAL VINE (*Antigonon leptopus*: Polygonaceae)—Native to tropical America, this herbaceous twiner has been in Florida since before 1916

TABLE 1. Floristic comparison of native and exotic phanerogamic climbers by region.

Site	Total Flora		Vine Flora					Source
	All Plants	% Vines	Natives	% Natives	Exotics	% Exotic	Total Vines	
Kentucky	3142	4%	93	2.9%	33	26%	126	Browne & Althey, 1992
Georgia	3686	4%	126	3.4%	25	17%	151	Jones & Coile, 1988
Fla. panhandle	2359	5%	96	4%	25	21%	121	Clewell, 1982
S. Florida	1647	9%	101	6%	50	33%	151	Long & Lakela, 1971
Sonoran Desert	2429	7%	170	100%	0	0%	170	Rundel & Franklin, 1991
Cuba	6375	8.4%	481	8%	57	10.6%	538	Borhidi, 1991
Panama (Barro Colorado Isl.)	1369	20.1%	265	100%	0	0%	265	Croat, 1978

TABLE 2. Summary of critical data on climber species on the Exotic Pest Plant Council 1997 "Invasive" list.

Scientific Name	Common Name	Introduction	Reason	Nativity & Other
Abrus precatorius	Rosary pea	1887–1888	ornamental	Old World tropics
Antigonon leptopus	Coral vine	pre-1916	ornamental	Mexico
Aristolochia littoralis	Calico flower	1893–1894	ornamental	South America
Colubrina asiatica	Lather leaf	pre-1933	?ornamental	se Asia
Cryptostegia madagascariensis	Madagascar rubber vine	pre-1933	agriculture (rubber)	Madagascar; confused with *C. grandiflora,* Palay rubber vine
Dioscorea alata	Winged yam	1897	agriculture (food?)	India to Malay Peninsula
Dioscorea bulbifera	Air potato	1905	agriculture (food & ornamental)	e Asia
Dioscorea sansibarensis	yam	1990s	religious plant?	Africa
Epipremnum pinnatum	Pothos, Jacob's coat	pre-1949	ornamental	Solomon Islands
Hiptage benghalensis	Hiptage	pre-1960s	ornamental	India
Ipomoea aquatica	Water spinach	pre-1950s	agriculture (food)	Asia
Jasminum dichotomum	Gold Coast jasmine	ca 1906	ornamental	tropical Africa
Jasminum fluminense	Jasmine	1916	ornamental	tropical Africa
Jasminum sambac	Arabian jasmine	1887–1888	ornamental	probably Asia
Lonicera japonica	Japanese honeysuckle	1875	ornamental	Japan
Lygodium japonicum	Japanese climbing fern	late 1800s	ornamental	e temperate Asia
Lygodium microphyllum	Old world climbing fern	late 1800s	ornamental	tropical Asia
Macfadyena unguis-cati	Cat's claw	pre-1947	ornamental	tropical America
Merremia tuberosa	Wood rose	pre-1913	ornamental	tropical America
Paederia crudassiana	Sewer plant	?pre-1993	?ornamental	se Asia
Paederia foetida	Sewer plant, Skunk vine	1897	agriculture (fiber)	se Asia
Passiflora foetida	Stinking passion-flower	1960s	ornament	American tropics
Pueraria montana	Kudzu	1899	agriculture; ornamental	China, Japan
Senna pendula	Climbing cassia	pre-1933	ornamental	South America; = *Cassia surattensis*; *C. colutoides*; *C. bicapsularis* misapplied
Solanum tampicense	Aquatic soda apple	1983	accidental	Mexico, Belize & Caribbean
Syngonium podophyllum	Nephthytis, Arrowhead vine	1979	ornamental	Mexico to Panama
Tribulus cistoides	Puncture vine, burnut	1940s?	accidental	American tropics?
Wedelia trilobata	Wedelia	pre-1933	ornamental	tropical America
Wisteria sinensis	Chinese wisteria	1887–1888	ornamental	Asia

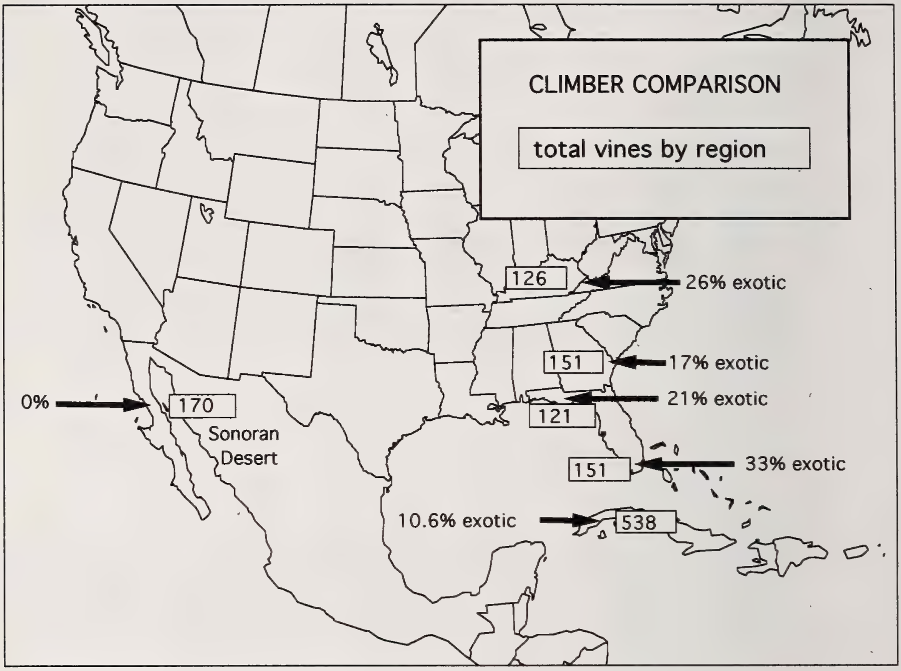


FIG. 1. Climbers in sample areas of the North American flora. Floras mentioned in the text were used to calculate the numbers of species in each region and the percentages these represented of the total climber flora.

(Simpson, 1916); Gordon and Thomas (1994) said before 1924. The plants grow from a large root and may simply be persisting from cultivation in southern Florida. However, there is abundant seed set in central part of the state. *Antigonon* is still sold in nurseries (Galleta, 1994).

CALICO FLOWER (*Aristolochia littoralis*: Aristolochiaceae)—Formerly this vine was called *A. elegans*. This South American species is found in several central Florida counties, from Alachua to Highlands. *Aristolochia* was offered for sale by the "Royal Palm Nurseries" in 1893–94 (R. Pemberton, 1997). Bailey (1949), and Hortus Third (Hortorium, 1976) both list the species. Wunderlin (1982) recorded that it had escaped from cultivation. Galleta (1994) still lists unnamed species of the genus for sale in the state.

LATHER LEAF (*Colubrina asiatica*: Rhamnaceae)—Native to southeastern Asia, this scrambling shrub was first recorded by John K. Small (1933) in "S pen. Fla. and the Keys." Later the species started becoming a pest in Dade and Monroe Cos. (Long & Lakela, 1971), and spread north to Martin Co. (Austin, 1978). Saponins in the bark are poisonous and are used medicinally by Asians (R. Pemberton, 1997). These plants out-compete native coastal vegetation, reducing diversity. Apparently the plants have been cultivated for ornament; may be dispersed by birds. Large colonies dominate saline sites in the Nature Conservancy's Blowing Rocks Park (Martin Co.) and Big Pine Key Refuge (Monroe Co.).

MADAGASCAR RUBBER VINE (*Cryptostegia madagascariensis*: Asclepiadaceae)—This native of Madagascar was introduced some time before 1933 (Gordon and Thomas, 1994). Most of the specimens that Long and Lakela (1971) called *C. grandiflora* are actually *C. madagascariensis* (Wunderlin, 1996). Perhaps this is what both Simpson (1916) and Fairchild (1947) also mentioned. The species is established in mangroves on the Florida southwestern coast from Everglades National Park (Monroe Co.) to Manatee Co. *Cryptostegia* is still sold in nurseries (Galleta, 1994). Fruits and seeds are spread by water.

AIR POTATO and WINGED YAM (*Dioscorea bulbifera* & *D. alata*: Dioscoreaceae)—These vines are native of southeastern Asia and Africa. *Dioscorea bulbifera* was sent by the United States Department of Agriculture to Florida horticulturist Henry Nehrling in 1905 (Morton, 1976). Nehrling said that, "...with the exception of kudzu vine I have never seen a more aggressive and dangerous weed in Florida" (quote in Morton, 1976). Plants are still grown and sold for ornament. The vines are invading wild tracts in Fakahatchee Strand State Preserve (Collier Co.), Castellow Hammock County Park (Dade Co.) and many other places in the peninsula, and even the Panhandle.

Dioscorea alata (Winged yam) has been recorded throughout the peninsula (Wunderlin et al., 1996) and is producing the same problems as *D. bulbifera.* Winged yam was offered for sale by the "Royal Palm Nurseries" in 1897 (R. Pemberton, 1997). Roger Hammer (1996) found *D. sansibarensis* in the Big Cypress after learning that it had been introduced into Dade Co., perhaps by Santarias.

POTHOS (*Epipremnum pinnatum*: Araceae)—A native of Solomon Islands, this plant was already in cultivation by the 1940s (Bailey, 1949), although the USDA listed it as introduced in the 1970s (Gordon and Thomas, 1994). Exactly when it escaped into the wild is not recorded, but plants are widespread in many of the Environmentally Sensitive Lands purchased by different counties in southern Florida. For example, pothos is abundant in Broward Co. at Flamingo Road and Fern Forest. Perhaps the species has only recently begun to fruit and seed successfully. Plants grow in the wild from Palm Beach through Dade Counties.

HIPTAGE (*Hiptage benghalensis*: Malpighiaceae)—This native of India was first reported in the wild by Roger Hammer and John Popenoe (15 May 1990) in Secret Woods Nature Center in Ft. Lauderdale (Broward Co.). Later it was found escaping at Fairchild Tropical Garden, Miami (T. Hendrickson, 1992). Plants in Broward Co. flowered in December 1990 near Christmas. Vines then fruited abundantly, and seedlings are now widespread in the park. Wind and probably water disperses the fruits.

WATER SPINACH (*Ipomoea aquatica*: Convolvulaceae)—The species has a long history in Asia, beginning with the Chin Dynasty (290–307 A.D.) in China (Burkill, 1935). The *Ipomoea* was long ago proposed as a commercial food crop in Florida, but did not materialize (Ochse, 1951; Ng, 1954; Edie & Ho, 1969). This commonly eaten food plant from Asia was introduced into Florida before the 1950s (Gordon and Thomas, 1994). Exactly when it was introduced is less important than recent events regarding the species.

With the influx of Asian immigrants in the 1970s–1990s this vine has been in growing demand, and it is being raised illegally throughout the state. Although listed on both the Florida and Federal noxious weed lists (DEP, 1992), *Ipomoea aquatica* is now being grown "legally" in Florida, under permit for export only. Without a permit, or when sold in the state, DEP considers "Possession of Chinese water spinach . . . a second degree misdemeanor . . . punishable by a $500 fine and/or 60 days in jail." Plants have invaded a number of Florida waterways near Tampa and in the Indian River and threaten to cause more problems in the future.

Fragments of the plants and seeds are spread to new sites by water. In Asia, where the species is native, it is a ubiquitous vine on canals and other waterways.

JASMINE, GOLD COAST JASMINE (*Jasminum dichotomum, J. fluminense, J. sambac*: Oleaceae)—These three jasmines are native to tropical Africa and Asia. *Jasminum sambac* was offered for sale by the "Royal Palm Nurseries" in 1887–88 (R. Pemberton, 1997). David Fairchild and J. M. Dalziel introduced *J. dichotomum* about 1906 (P. I. 73067) from the African Gold Coast (now Ghana). Fairchild and P. H. Dorsett introduced *J. fluminense* in 1916; it was introduced again in 1931 and 1932 from different places. *Jasminum* has been a troublesome pest in the Caribbean for years. Birds spread the fruits, and the plants grow from Highlands County to the Florida Keys.

By the early 1940s David Fairchild was worried about the first two species. He found birds spreading them around and feared being remembered as the "Damnable Introducer of Weeds" (Fairchild, 1947). Read (1962) discussed the nomenclatural confusion regarding these vines, and gave details of introductions not found elsewhere.

HONEYSUCKLE (*Lonicera japonica*: Caprifoliaceae)—Perhaps the most loved and hated vine in North America, these plants were introduced as ornamentals in 1875. They long ago escaped and have overrun many communities. Birds spread the fruits, and honeysuckle is established throughout the Panhandle and south to the Tampa region.

OLD WORLD CLIMBING FERN (*Lygodium microphyllum*: Schizaeaceae)—Native to Africa, Asia and Australia (Brock, 1988), the climber was first found in the wild near the Palm Beach and Martin Co. line in Florida in the late 1960s. The expanded range was discussed by Nauman and Austin (1978).

The fern was introduced and sold commercially by Reasoner's nursery in the late 1800s (R. Pemberton, 1997). *Lygodium* continues being spread as a weed in potted horticultural plants. Since the 1970s the species has moved north and south. These ferns climb tens of meters into the margins of cypress swamps and other wetlands. Once established, they shade out native species and reduce diversity. This is the alien pest equivalent of Kudzu vine in southern Florida.

Another species, *L. japonica,* is causing similar problems in central and northern Florida (Wunderlin, 1982, Clewell, 1985). R. Pemberton (1997) is working on a more complete discussion of the species.

CAT'S CLAW (*Macfadyena unguis-cati*: Bignoniaceae)—Julia Morton (1976) and Fairchild (1947) recorded that this climber was introduced before 1947. Fairchild was using it as an ornamental, and loved its golden flowers. The species is native from the Caribbean to Argentina where it grows in forests.

This vine is tolerant of wide variations in growing conditions and thrives in peninsular Florida; also the arid zones of the Sonoran desert in Phoenix, AZ. Probably it was brought into cultivation because of its showy yellow flowers. Winged seeds are spread by the wind. Once established, the seedlings produce large storage roots at low light levels before growing vigorously into the forest canopy.

WOOD ROSE (*Merremia tuberosa*: Convolvulaceae)—This tropical American native came under scrutiny after Hurricane Andrew. No one records when it was introduced. Neither Gray (1886) nor Chapman (1897) recorded the species here, but a few years later Small (1913) and Simpson (1916) found it. After Hurricane Andrew wood rose covered many of the damaged hammocks, retarding recovery. The species did much the same in Guam after World War II (R. Fosberg, 1974), but is rare there now (Walker, 1976). Perhaps it will be a temporary problem in Florida also.

SKUNK VINE (*Paederia crudassiana, P. foetida*: Rubiaceae)—These climbers are native in the Indian Himalayas, China, the Philippines and the Malay Peninsula (Puff, 1991). The species was introduced for a fiber crop, and used as an ornamental (Pankowski, 1992, Hall, 1993), but surely a curiosity also. The binomial refers to the bad smell, and is the least vulgar of the names used for the plant. In China one name means "chicken excrement plant"; in the Malay Peninsula *akar sekentut* refers to its fecal smell; a related species in Okinawa is called *hekuso-kazura* or the flatulent vine.

Plants are cultivated from at least Tallahassee south to Miami, and have been recorded as escaped in about half of the counties. Where it does occur in moist to wet native landscapes, or even in cultivation, the vine often covers vast areas (Pankowski, 1992). Spread from place to place seems to be by animal vectors carrying the fleshy, colored drupes. Once established, the runners allow single plants to cover several acres.

STINKING PASSION-FLOWER (*Passiflora foetida*: Passifloraceae)—Austin (1976) and Morton (1976) independently reported the species in the wild in Palm Beach Co. and in Dade Co., Florida. These foci probably resulted from separate introductions. By the early 1900s the species was being touted as a good butterfly plant even though our native species better serve these insects (Austin, 1993). Many acres are covered in southeastern Florida with this tropical pest. Bright red fruits attract birds that spread the seeds.

KUDZU (*Pueraria montana*: Fabaceae)—Officially these vines were introduced in 1899 from the China and Japan region where they are native. David Fairchild (1947) brought them into Dade County in the early 1900s.

Southern Florida may not have as much a problem with this species as we were afraid in 1992 when it was re-discovered. It turns out that the species was introduced into the Conservation Areas by the USDA when they planted these vines in 1952 (Stephens, 1952). T. Hendrickson and A. Buckley (1994) found them in 1980, but no one took notice or showed concern with their discovery. So, the species has been in Broward Co. about 44 years, and in Dade for perhaps 80 or 90 years, without appreciable spread. It is too bad that this is not also true for northern Florida and the remaining southeastern states.

CLIMBING CASSIA (*Senna pendula* var. *glabrata* [= *Cassia bicapsularis* misapplied, = *C. surattensis* misapplied, = *C. coluteoides*]: Fabaceae)—Introduced from tropical America. We do not know when it was first introduced; not listed by Chapman (1897) or Small (1913), but included as *C. bicapsularis* by Small (1933) and Bailey (1949). Climbing Cassia was uncommon in wetlands in southern Florida when I came here in 1970. I found them still cultivated in Tampa in 1979–1980 when I was on sabbatical there.

In the past few years these vines have become more prevalent in wetland habitats throughout the peninsula from Hillsborough and Brevard counties south. The species often becomes established in openings and then persists as these close by climbing over the canopy.

AQUATIC SODA APPLE (*Solanum tampicense*: Solanaceae)—This species was not listed by the 1993 EPPC committee (Gordon and Thomas, 1994), being first included in 1997 (EPPC, 1997). Fox and Wigginton (1996) recorded the history of invasion of this species, beginning with its first discovery in 1983 at Punta Gorda. This soda apple grows along stream and riverbanks where it forms impenetrable prickly thickets to the exclusion of natives. Now the plant is known from Highlands to Monroe County on Florida's west coast.

NEPHTHYTIS (*Syngonium podophyllum*: Araceae)—It is unfortunate that the horticultural trade has taken up the name "nephthytis" and "African evergreen," for this tropical America plant. *Nephthytis* is a distinct African genus. These plants are also called "arrowhead vine." The species is native from Mexico to Panama, and is said to have been introduced in 1979 (Gordon and Thomas, 1994). *Syngonium* is still sold in nurseries (Galleta, 1994). Plants are established in wild areas from Brevard and Hillsborough counties south to Monroe County.

PUNCTURE VINE (*Tribulus cistoides*: Zygophyllaceae)—The story is told that this Old World species was spread around the world during World War II by fruits sticking into airplane tires. Whether or not this is true, the plants were concentrated originally near military bases in southern Florida shortly after the war. Subsequently, their effective dispersal by adhering to virtually anything by the spines on their "caltrop" fruits moved them to all habitats. Although requiring abundant sunlight to thrive, they have moved into many native communities, particularly beaches. These procumbent vines are established from Brevard and Hillsborough counties south to Monroe County.

WEDELIA (*Wedelia trilobata*: Asteraceae)—This widely used ornamental was introduced some time before 1933 (Gordon and Thomas, 1994). Not only does this species appear in numerous preserves throughout the peninsula where it competes with native plants by crowding and overtopping, but it is too rampant for some gardeners. Still, the plants are spread by horticulturists.

According to R. Knight (1994) the plant is self-incompatible, but it "spreads quite nicely without seeds." Herbarium records exist for escapees in 16 counties, mostly peninsular Florida (Wunderlin et al., 1996).

CHINESE WISTERIA (*Wisteria sinensis*: Fabaceae)—Introduced from China, this vine has long been cultivated in the southeastern United States. *Wisteria* was offered for sale by the "Royal Palm Nurseries" in 1887–88 (R. Pemberton, 1997). Simpson (1916) said that this and other species "do well in the cooler parts of Florida." Before the early 1980s it was spread through the northern half of the peninsula (Wunderlin, 1982).

ACKNOWLEDGMENTS—Based on a talk given at the EPPC Climbing (twining) ferns and invasive exotic vines workshop, 3 Apr. 1996. Thanks for various data are due Michael Bodle, Amy Ferriter, François Laroche and Dan Thayer (South Florida Water Management District, West Palm Beach), Kathy Burks and Greg Jubinksy (Department of Envoronmental Protection, Tallahassee), Richard Wunderlin (University of South Florida, Tampa), Richard Moyroud (Florida Native Plant Society, West Palm Beach Chapter), Nancy Coile (Florida Department of Agriculture and Consumer Services, Gainesville), Doria Gordon (The Nature Conservancy, Gainesville), and Daniel B. Ward (University of Florida, Gainesville). Robert Pemberton (USDA, Davie) provided data on Asian uses of plants, and on dates of introduction. Roger Hammer (Department of Environmental Resources Management, Miami) provided information on exotics in Dade Co. Ted Hendrickson and Ann Buckley (Broward Co.) rediscovered *Pueraria* in Conservation Area 2 after knowledge of its being planted there was lost.

LITERATURE CITED

AUSTIN, D. F. 1976. Vegetation of southeastern Florida—I. Pine Jog. Florida Scient. 39:230–235.

———. 1978. Exotic plants and their effects on southeastern Florida. Environm. Conserv. 5(1): 25–34.

———. 1993. Stinking passion flower. The Palmetto 13(3):5.

———. 1994. Creepers, climbers, vines and wines. The Palmetto 14(3):6.

BAILEY, L. H. 1949. Manual of Cultivated Plants. Macmillan Co., New York, NY.

BALFOUR, D. A. AND W. J. BOND. 1993. Factors limiting climber distribution and abundance in a southern African forest. J. Ecol. 81:93–99.

BORHIDI, A. 1991. Phytogeography and Vegetation Ecology of Cuba. Akadémiai Kiadó, Budapest.

BROCK, J. 1988. Top End Native Plants. Published by author, Darwin.

BROWNE, E. T. J. AND R. ATHEY. 1992. Vascular Plants of Kentucky. An Annotated Checklist. University Press of Kentucky, Lexington, KY.

BURKILL, I. H. 1935. A Dictionary of the Economic Products of the Malay Peninsula. Vol. II, pp. 1270–1271. Reprinted in 1966, Ministry of Agriculture, Kuala Lumpur.

CHAPMAN, A. W. 1897. Flora of the Southern United States. Cambridge Botanical Supply Co., Cambridge, MA.

CLEWELL, A. F. 1985. Guide to the Vascular Plants of the Florida Panhandle. University Presses of Florida/Florida State University Press, Tallahassee, FL.

COLLINS, B. S. AND G. R. WEIN. 1993. Understory vines: distribution and relation to environment on a southern mixed hardwood site. Bull. Torrey Bot. Club 120:38–44.

CROAT, T. B. 1978. *Flora of Barro Colorado Island.* Stanford Univ. Press, Stanford, CA.

DEP. 1997. EPPC exotic database, Department of Environmental Protection, Tallahassee, FL.

———. 1992. Weed Alert. Water Spinach (*Ipomoea aquatica*). Florida Department of Natural Resources, Tallahassee, FL.

EDIE, H. H. AND B. W. C. HO. 1969. *Ipomoea aquatica* as a vegetable crop in Hong Kong. Econ. Bot. 23:32–36.

EPPC. 1995. Exotic Pest Plant Council's 1995 list of Florida's most invasive species. Resource Management Notes 6(6):19–26.

———. 1997. Exotic Pest Plant Council, Invasive Plant Committee, Web Sites: http://www.fau.edu/divdept/biology/people/eppc97.htm and http://www.fleppc.org.

FAIRCHILD, D. 1947. The World Grows Round My Door. Charles Scribner's Sons, New York, NY.

FOSBERG, R. 1974. Department of Botany, Smithsonian Museum of Natural History, Washington, D.C., Pers. Comm.

FOX, A. AND A. WIGGINTON. 1996. Wet and wild: Aquatic soda apple—The wetland weed from Hell. Florida EPPC Newsletter 6(4):2–3.

GALLETA, K. 1994. Plantfinder. Betrock Information Systems, Inc., Hollywood, FL.

GORDON, D. R. AND K. P. THOMAS *In*: SCHMITZ, D. C. AND T. C. BROWN. (ed.). 1994. An

Assessment of Invasive Non–Indigenous Species in Florida's Public Lands. DEP, Bureau of Aquatic Plant Management, Technical Report No. TSS-94-100, Tallahassee, FL.

GRAY, A. 1886. Synoptic Flora of North America. Ivison, Blakeman, Taylor & Co., New York, NY.

HALL, D. 1993. Illustrated Plants of Florida and the Coastal Plain. Maupin House Publishing, Gainesville, FL.

HANNER, R. AND J. POPENOE. 1990. Broward County Parks Department and Fairchild Garden, Pers. Comm.

———. 1996. Yamming it up in Big Cypress. EPPC Newsletter Fall 6(4):7.

HENDRICKSON, T. AND A. BUCKLEY. 1992. 1994. Naturalists, Broward Co., Ft. Lauderdale, Pers. Comm.

HORTORIUM, L. H. B. 1976. Hortus Third. Macmillan Publishing Co., New York, NY.

JONES, S. B. JR. AND N. C. COILE. 1988. The Distribution of the Vascular Flora of Georgia. Department of Botany, University of Georgia, Athens, GA. 230 pp.

KNIGHT, R. 1994. United States Department of Agriculture, Miami, FL, Pers. Comm.

LONG, R. W. AND O. LAKELA. 1971. A Flora of Tropical Florida. University Miami Press, Miami, FL.

LOTT, F. J., S. H. BULLOCK, AND J. A. SOLÍS-MAGALLANES. 1987. Floristic diversity and structure of upland and arroyo forests of coastal Jalisco. Biotropica 1:228–235.

MOLINA-FREANER, F. AND C. TINOCO-OJANGUREN. 1997. Vines of a desert plant community in Central Sonora, Mexico. Biotropica 29:46–56.

MORTON, J. F. 1976. Pestiferous spread of many ornamental and fruit species in South Florida. Proc. Florida Hort. Soc. 89:348–353.

NAUMAN, C. AND D. F. AUSTIN. 1978. Spread of the exotic fern *Lygodium microphyllum* in Florida. Amer. Fern J. 68:65–66.

NG, C. L. 1954. A proposal to introduce wet-land cultivation of water spinach (in Chinese). Taiwan J. Agric. Forestry 8:24–25.

OCHSE, J. J. 1951. Two vegetables for south Florida. Proc. Florida State Hort. Soc. 64:106.

PANKOWSKI, K. 1992. Fast-growing vine at root of park's troubles. The Orlando Sentinal. pp. D-2, D-6. 19 Oct.

PEMBERTON, R. 1997. United States Department of Agriculture, Davie, Pers. Comm.

PUFF, C. 1991. The Genus *Paederia* L.: a multidisciplinary study. Meise, Belgium.

PUTZ, F. E. 1984. The natural history of lianas on Barro Colorado Island, Panama. Ecology 65: 1713–1724.

——— AND P. CHAI. 1987. Ecological studies of lianas in Lambir National Park, Sarawak. J. Ecol. 75:523–531.

READ, R. W. 1962. *Jasminum* species in cultivation in Florida and their correct names. Proc. Florida Hort. Soc. 75:430–437.

RUNDEL, P. W. AND T. FRANKLIN. 1991. Vines in arid and semi-arid ecosystems. Pp. 337–356. *In*: PUTZ, F. E. AND H. A. MOONEY (eds.). The Biology of Vines. Cambridge University Press, Cambridge, England.

SIMPSON, C. T. 1916. Ornamental Gardening in Florida. Little River, Publ. by the author.

SMALL, J. K. 1913. Flora of Miami. Publ. by author, New York, NY.

———. 1933. Manual of the Southeastern Flora. University North Carolina Press, Chapel Hill, NC.

STEPHENS, J. C. 1952. Annual Report. Everglades Project R-4-I. United States Department of Agriculture, Soil Conservation Service, Research Division of Drainage and Water Control, Washington, DC.

WALKER, E. H. 1976. Flora of Okinawa and the Southern Ryukyu Islands. Smithsonian Institution Press, Washington, DC.

WUNDERLIN, R. P. 1982. Guide to the Vascular Plants of Central Florida. University Presses of Florida/University South Florida Press, Tampa, FL.

———. 1996. University of South Florida, Tampa. Pers. Comm.

———, B. F. HANSEN, AND E. L. BRIDGES. 1996. University of South Florida, Tampa, Web Site: http://www.usf.edu/~isb.

Florida Scient. 61(2): 106–117. 1998
Accepted: October 14, 1997

EFFECTS OF SUBMERGENCE ON EMBRYONIC SURVIVAL AND DEVELOPMENTAL RATE OF THE FLORIDA APPLESNAIL, *POMACEA PALUDOSA*: IMPLICATIONS FOR EGG PREDATION AND MARSH MANAGEMENT

Richard L. Turner

Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975

Abstract: *Aerial deposition of egg clutches by the aquatic Florida applesnail is believed to have evolved in response to aquatic egg predators. Adaptation to aerial conditions might, however, have rendered embryos intolerant of submergence, a potential occurrence in natural and managed marshes, rivers, and lakes. In this study, eggs were submerged in water for various durations in the laboratory to assess their ability to survive flooding; and clutches of known ages were submerged for several days in the field to determine if aquatic predators might decrease survival below levels expected to occur due to flooding alone. Submergence of clutches slowed embryonic development and increased mortality. Embryos that were within a few days of hatching at the time of submergence were not strongly affected. When younger embryos were submerged, none hatched; and most died in early stages of growth. Submergence of clutches in the field increased mortality above that in laboratory submergence, but factors other than predation, such as loss of adhesion and entanglement with floating debris, accounted for the losses. There was no evidence that aquatic predators were a significant factor in embryonic mortality. In managed wetlands that hold populations of* Pomacea paludosa*, flooding should occur slowly during the reproductive season (March through October), particularly in the first few months when clutch production is high, to avoid loss of as much as 2 wk of clutch production.*

Ampullariid snails (applesnails) of the genera *Pomacea* Perry and *Pila* Roeding deposit clutches of large eggs with calcareous shells on emergent vegetation of freshwater habitats (Perera and Walls, 1996). The two genera have long fossil histories, and there are numerous reports of the Florida applesnail, *Pomacea paludosa* (Say), in fossil strata since the late Pliocene (2 mya) (Dall, 1892; Tucker and Wilson, 1932; Henderson, 1935; Smith, 1937; Taylor, 1966; Hoerle, 1970; McGinty, 1970; Thompson, 1984; Petuch, 1992; Perera and Walls, 1996). It is generally believed that the New World genus *Pomacea* evolved the habit of aerial deposition of clutches in response to loss to aquatic predators such as its sympatric confamilial *Marisa* Gray (Robins, 1971; Paulinyi and Paulini, 1972), which deposits submerged gelatinous clutches (Perera and Walls, 1996). Because mean elevation of clutches above the surface of the water is only 150–200 mm (Hanning, 1979; Turner, 1996), a moderate rise in water level of 11–14 mm/d would submerge many clutches during the 2-wk period of development, potentially subjecting embryos to physiological stress and aquatic predators. The purpose of this study was to measure the physiological tolerance of embryos to submergence and to evaluate the potential of aquatic predation to reduce further the survival of embryos.

METHODS—Clutches were collected from emergent stems (primarily common cattail, *Typha latifolia* L.) at a water-filled borrow pit (28° 7′ 24″ N, 80° 42′ 28″ W) northwest of the intersection of U.S. Interstate Highway 95 and Florida State Road 518, west of Melbourne, Florida. The lake, known locally but unofficially as Clear Lake, is steep sided and was formed by the excavation of carbonate rock to build the roadbed for the interstate highway. In addition to a dense, stable population of applesnails, Clear Lake contains *Lepomis microlophus* (Gunther) (redear sunfish) and *Trionyx ferox* (Schneider) (Florida soft-shelled turtle), known predators of adult applesnails (Chable, 1947; Wilbur, 1969; Dineen, 1974; Dalrymple, 1977), and several other species of *Lepomis* Rafinesque that possibly eat hatchling applesnails (Snyder and Snyder, 1971; Jaynes, 1993). Blue Cypress Water Management Area (BCWMA) East (described in Turner, 1996) contains the same predators (Snyder, 1997). Both Clear Lake and BCWMA East sites were used to study predation.

Clutches are laid at night within an adhesive mass of extracapsular mucus (jelly) that dries within a few hours after sunrise. Clutches that are found to be invested with jelly are, therefore, within several hours of oviposition. Jellied clutches were collected at Clear Lake in August and September 1993, transferred to standard (25 mm by 76 mm), glass, microscope slides, and allowed to dry in an inclined position under full-spectrum fluorescent lighting (Daylight, General Electric Co.) at 27–32°C and 59–82% relative humidity. The upright orientation of the clutch on the original plant stem was maintained during this study; i.e., care was taken not to invert the stem and clutch. When the clutches were dry, each was placed at a slight incline in a beaker and allowed to incubate under a photoperiod of 12 h of light and 12 h of darkness for 14 or 21 d. Each beaker was provided with at least a few millimeters of water into which hatchling snails could fall. During incubation, filtered lake water was added to the beakers to submerge selected clutches at ages of 1, 4, 8, and 12 d; the ratio of water volume to clutch volume was approximately 150:1. Control clutches were not submerged. Lake water was coarsely filtered (Whatman no. 1) to remove larger microorganisms.

After 14 or 21 d of incubation, clutches were removed for dissection to determine the stages and viability of embryos. Stages of development included hatchlings, shelled embryos, and unshelled embryos. To stage shelled embryos further, each embryo was placed over graph paper with 1-mm spacing, and the size of the body shell was estimated as the number of grid-squares covered. The following criteria, from most to least reliable, were used to recognize a live embryo: heartbeat; withdrawal of the body into the shell; active epidermal ciliation; foot expanded and appressed to an intracapsular gas bubble.

Low production of clutches at Clear Lake during the summer drought of 1993 precluded optimal experimental design: replication was low (r = 2 or 3), and the clutches had to be incubated in three trials. Each trial included two control clutches, but not all possible combinations of treatments (four ages at submersion and two days of sacrifice) were included in each trial. Additional jellied clutches were harvested at Clear Lake during April–May 1994 and allowed to develop in the laboratory at similar temperature, humidity, and lighting as in 1993. Clutches were dissected at regular intervals and evaluated for stage of development to produce a representative series of embryogenesis under aerial conditions.

The field phase of studies on submersion attempted to assess the potential of predation to inflict mortality before death that would be expected to have occurred by submergence alone (i.e., in the absence of predators) based on results of the laboratory phase. Jellied clutches were collected from emergent stems in Clear Lake in 1993 at regular intervals and held in the laboratory for later use. At the start of each of two trials, therefore, clutches of several ages were available for submergence. In addition, enough jellied clutches were found in Clear Lake at the start of the Clear Lake trial to include 0-d-old (jellied) clutches. The two trials were conducted at Clear Lake and BCWMA East. Ages for the Clear Lake trial were 0, 1, 4, 7, and 11 d; those for the BCWMA East trial 2, 6, 9, and 13 d.

Poles made from half-inch (21-mm outside diameter) polyvinylchloride (PVC) plumbing pipe were cut to 1.5-m lengths and driven vertically into the substratum. Clutches were attached by their plant stems to the PVC poles with plastic cable-ties, free ends of which were cut to reduce the chance of fouling by windblown or waterborne debris. Each pole held a pair of clutches of the same age, one clutch (aerial clutch) about 300 mm above the water level and one (submerged clutch) about 50 mm below the water level. At Clear Lake, 10 poles were set along the northern shore at water depths of 510–810 mm and secured to *Typha latifolia* with cable-ties. Pairs of clutches were assigned to the poles haphazardly, and they were oriented toward open water. At BCWMA East (27° 40′ 21.2″ N, 80° 38′ 19.2″ W), 15 poles were set in two ranks, one along the sawgrass (*Cladium jamaicense* Crantz) edge and the other within the nearby mixed shallow marsh and about 5.1 m from the sawgrass edge; depths were 280–440 mm. Assignment of clutches to poles was haphazard, and those on poles along the sawgrass edge faced open water.

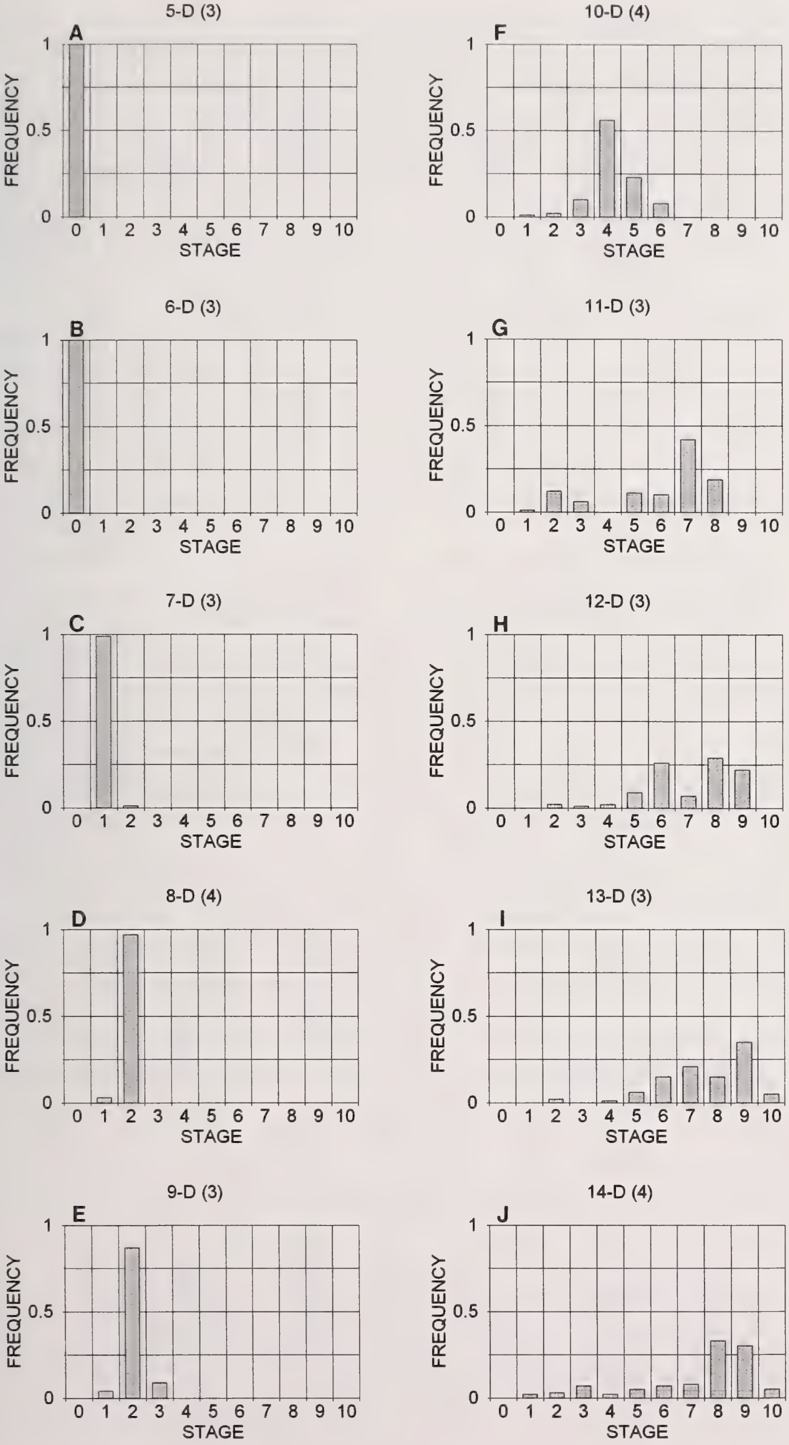
Visibility in the water column at Clear Lake was excellent: The bottom of the lake at the base of the PVC poles could be seen from the surface, and there was no macroscopic debris floating or suspended in the water. Visibility at BCWMA East was poor: *Utricularia vulgaris* L. (common bladderwort) and plant debris filled nearly the entire water column along the sawgrass edge and in the mixed shallow marsh; only a few centimeters of free water remained at the surface. During these trials, water level dropped about 30 mm at Clear Lake and about 20 mm at BCWMA East, leaving none of the submerged clutches exposed. Clutches were harvested after 3 d in June 1993 in the Clear Lake trial and after 7 d in July 1993 in the BCWMA East trial. Notes on gross condition of clutches and eggs were made in the field and laboratory, and eggs from the BCWMA East trial were individually dissected.

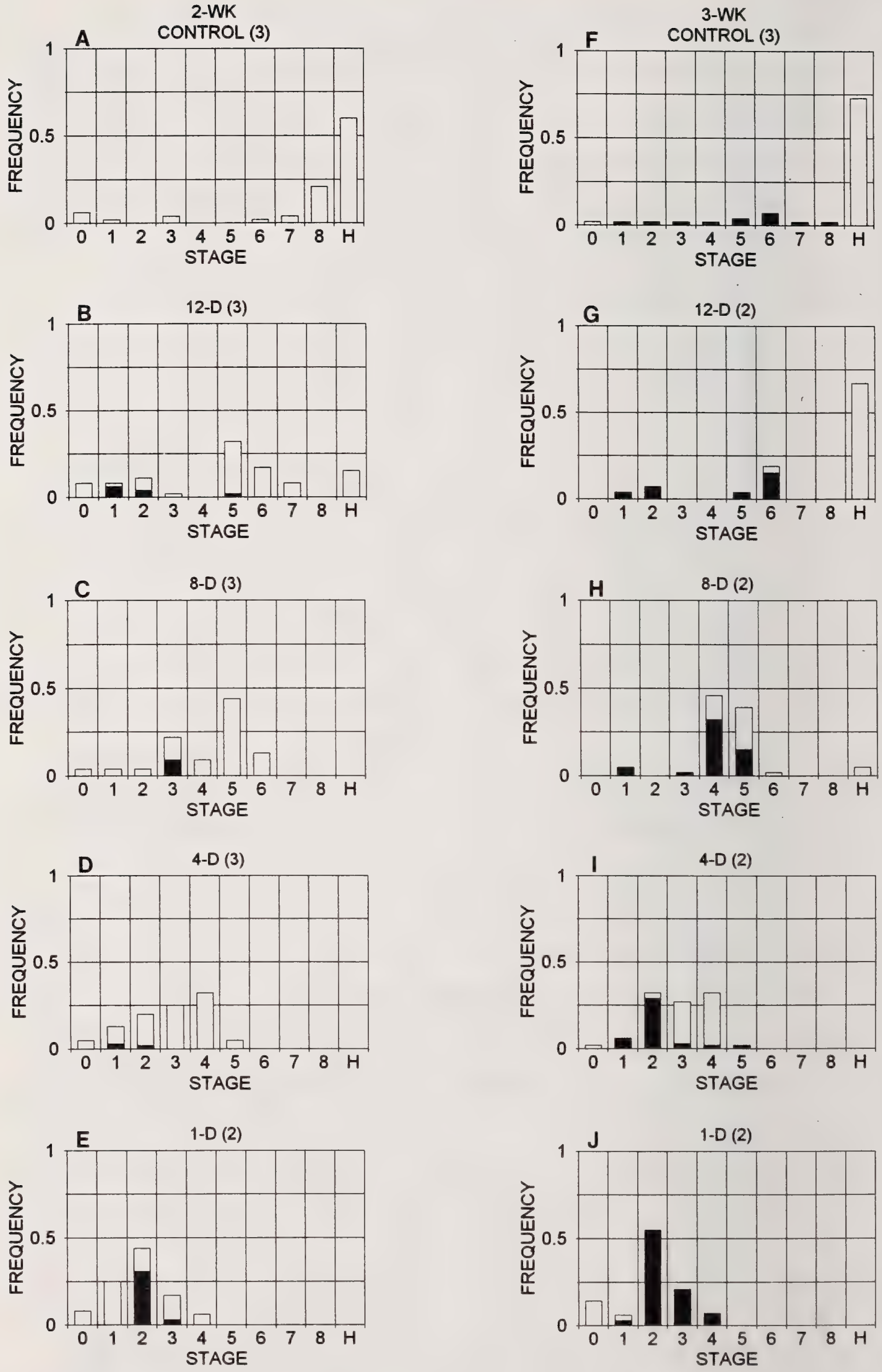
RESULTS—Under aerial conditions in the laboratory, embryos of *Pomacea paludosa* remained small (< 1 mm square) and lacked a body shell for the first 4 d of development. Shelled embryos reached Size-class 1 (1 mm square) by Day 7 and grew slowly to Size-class 4 at 10 d, by which time the size distribution spread over six classes (Fig. 1F). As embryogenesis progressed, the modal size class decreased in frequency (Fig. 1F–H), and the distribution became increasingly skewed toward the smaller size classes. By Day 14, 68% of the embryos had attained size-classes 8–10 (Fig. 1J). Clutches at 14 d were sacrificed before hatching occurred.

Submergence in all treatments slowed the rate of embryonic development and increased mortality in the laboratory (Fig. 2). The severity of effects was directly proportional to the duration of submergence and inversely proportional to age at submergence. Nevertheless, submerged embryos in all treatments continued to grow beyond their predicted size at time of submergence (cf. Fig. 1 and Fig. 2). For example, embryos submerged

→

FIG. 1. Relative size-frequencies of shelled embryos of *Pomacea paludosa* under aerial conditions in the laboratory. No embryo of clutches sacrificed before 5 d of incubation bore a body shell. Values in parentheses are the numbers of clutches used.


5-D (3)
A
10-D (4)
F
6-D (3)
B
11-D (3)
G
7-D (3)
C
12-D (3)
H
8-D (4)
D
13-D (3)
I
9-D (3)
E
14-D (4)
J
FREQUENCY
0
0.5
1
STAGE
0 1 2 3 4 5 6 7 8 9 10


A
2-WK
CONTROL (3)
F
3-WK
CONTROL (3)
B
12-D (3)
G
12-D (2)
C
8-D (3)
H
8-D (2)
D
4-D (3)
I
4-D (2)
E
1-D (2)
J
1-D (2)
FREQUENCY
0
0.5
1
STAGE
0 1 2 3 4 5 6 7 8 H

at 8 d at a predicted Size-class 2 (Fig. 1D) attained size-classes 3–6 during the subsequent 6 d of submergence (Fig. 2C).

Success of hatching after 14 d was highest in the control (aerial) group, and the modal size of unhatched embryos in the controls was the largest of all groups (Fig. 2A). Moderate hatching occurred in clutches submerged at 12 d of age (Fig. 2B), but hatching did not occur in any clutches submerged at younger ages (Fig. 2C–E). Growth was retarded in all submerged clutches compared to the control (Kolmogorov-Smirnov test for goodness of fit to an extrinsic hypothesis, $P < 0.05$ for each of four comparisons, n = 23–60). Although modal size declined in clutches submerged at younger ages, submergence did not arrest growth. For example, after 14 d of embryogenesis, clutches submerged at ages of 4 d and 1 d (Fig. 2D, E) grew body shells of sizes equivalent to those of 8–10-d embryos incubated under aerial conditions (Fig. 1D–F). Mortality occurred only in submerged clutches; total embryonic mortality during the first 14 d of incubation was 12% of unhatched shelled embryos, and 97% of all deaths occurred among the smallest embryos (size-classes 0–3).

Extension of incubation time to 21 d (Fig. 2F–J) did not allow embryogenesis to progress except in control clutches and in clutches submerged at 12 d of age, as shown in the increased proportion of hatchlings. The two juveniles that hatched in the 8-d group (Fig. 2H) fell from the uppermost eggs of one clutch that had become partly exposed due to excessive evaporation in the beaker. Mortality was 67% among unhatched shelled embryos of clutches incubated for 21 d.

Submergence of clutches in the field gave little evidence for loss to aquatic predators. Only 5 of the 309 eggs in 10 aerial clutches were damaged during the 3-d trial at Clear Lake (93–100% survival; Table 1). There was no evidence of hatching in aerial clutches or of damage due to recreational use of jet-propelled watercraft. Two additional eggs from one aerial clutch were lost entirely from their attachment to the plant stem; the same clutch included two broken eggs. Survival of eggs in submerged clutches at Clear Lake was much lower and more variable (44–99%; Table 1). Of 362 eggs in 10 submerged clutches, 19 were broken; but 12 were empty of contents (no residual yolk or albumen) and belonged to clutches for which control clutches in the laboratory began hatching on the date that this trial was concluded; the other seven were on PVC poles that sustained loss or damage

---

←

FIG. 2. Effects of laboratory submergence on relative size-frequencies of embryos. Clutches were submerged at ages 12, 8, 4, or 1 d and remained submerged until the day of sacrifice. Controls were not submerged. A–E, clutches sacrificed after 2 wk of incubation. F–J, clutches sacrificed after 3 wk of incubation. Stage 0 included only embryos that lacked a body shell. Hatchlings (H) were not sized. Shelled embryos were scored as live (white parts of histogram bars) or dead (black), but unshelled embryos could not be scored. Values in parentheses are the numbers of clutches used.

TABLE 1. Condition of paired aerial and submerged clutches in the field. Two pairs of clutches were used for each age at Clear Lake and four pairs (three for 6-d-old clutches) at BCWMA East. Data do not include eggs that were damaged in handling at the start of the trial.

Age at start (d)	Percentage of eggs after 3 or 7 d in:							
	Aerial clutches				Submerged clutches			
	Whole	Lost	Broken	Hatched	Whole	Lost	Broken	Hatched
				Clear Lake, 3 d				
0	100	0	0	0	44.4	55.6	0	0
1	98.2	0	1.8	0	98.6	0	1.4	0
4	93.4	3.3	3.3	0	83.0	11.0	6.0	0
7	98.8	0	1.2	0	83.9	16.1	0	0
11	100	0	0	0*	70.5	9.8	19.7	0*
				BCWMA East, 7 d				
2	96.9	3.1	0	0	90.6	6.3	3.1	0
6	86.7	0	1.3	12.0	100	0	0	0
9	54.1	1.3	0	44.6	82.3	12.9	3.2	1.6
13	32.1	25.9	0	42.0	9.9	16.8	22.8	50.5

* Control clutches in laboratory began to hatch on last day of trial.

to their aerial clutches. Another 66 eggs were lost from submerged clutches: 40 from jellied, 0-d-old clutches, which presumably lost adhesion; 11 eggs from the PVC pole holding the aerial clutch that had 2 lost and 2 broken eggs; 6 from a submerged clutch that presumably had begun to hatch, based on hatching of control clutches in the laboratory; and 9 from a PVC pole with an aerial clutch in which 2 eggs were broken.

Dissection of eggs retrieved from the trial at BCWMA East after 7 d improved the ability to discriminate between hatching and other conditions of eggs. Survival of eggs was higher and less variable in aerial (74–99% whole and hatched eggs; Table 1) than in submerged clutches (60–100%). All but one egg were lost or crushed in a pair (i.e., aerial and submerged) of clutches on one PVC pole, indicating the occurrence of an unknown event. Except for this pair of clutches, 8 eggs were lost and 1 broken out of 333 eggs of 14 aerial clutches; and 31 eggs were lost and 11 broken out of 303 eggs of 14 submerged clutches. More than half of the eggs lost from submerged clutches represented an entire clutch on a pole that had become surrounded by floating debris; and 7 of the 11 broken eggs of submerged clutches were empty (no residual yolk or albumen) and belonged to clutches that had begun to hatch. Hatching rates of 13-d-old eggs were high and similar in submerged (50.5%) and in aerial (42.0%) clutches; and the rate for 9-d-old eggs was far poorer in submerged (1.6%) than in aerial (44.6%) clutches (Table 1).

DISCUSSION—The large gelatinous eggs of *Marisa cornuarietis,* in the same family as the Florida applesnail, are laid underwater (Perera and Walls, 1996). They swell from 3 mm diameter at oviposition to 5 mm as water is imbibed soon afterward (Michelson, 1955). It is not, therefore, valid to assume that the large eggs of *Pomacea paludosa,* with diameters of 4–6 mm (Ryder, 1889; Wallace et al., 1956; Hepler, 1974; Hanning, 1979), would die from submergence due to physiological stress. But the Florida applesnail has probably evolved a physiological dependence on aerial incubation. More than 100 yr ago, Ryder (1889) warned that submergence kills the embryos. Other authors since have parroted his warning, and only Hurdle (1973) has offered new data. Hurdle (1973) found submergence to delay hatching but not to prevent it. Submergence loosened the extracapsular adhesive mucus after 1 wk, and 45% of clutches lost eggs by detachment within 2 wk. Unfortunately, Hurdle's (1973) clutches were of unknown ages at the start of submergence, and he gave no data on mortality within clutches. A subsequent experiment (Hurdle, 1974) gave similar results, with submergence for 1 wk followed by a post-submergence period of continued embryogenesis; but no information was given on age of clutches or on mortality within clutches. In the present study, also, embryogenesis was delayed by submergence in the laboratory. After 3 wk, however, embryogenesis had not progressed beyond stages at 2 wk in clutches that were submerged at ages of 1, 4, and 8 d; and mortality at 21 d of incubation was high. Clutches that were submerged at 12 d of age had already achieved a moderate size of shelled embryo; some hatched within another 2 d and many by the end of the experiment at 21 d.

Many smaller embryos are capable of crawling when freed from their eggshells (Turner, unpublished observations), but only embryos with body shells similar in diameter to their eggshells will hatch. The mechanism of hatching is unknown in *P. paludosa.* Hatching does not seem to be aided by weakening of the eggshell by chemical dissolution or radular scraping, for inspection by scanning electron microscopy gives no evidence for either mechanism (Turner and McCabe, 1990). If hatching is size dependent, it might be accomplished by outward pressure from extension of the foot. Based on this hypothesis, submerged eggs would hatch only if they contained late-stage embryos that could achieve hatching size before death from physiological stress; and smaller embryos, competent to live if freed, would remain unhatched, lacking both the aid from implosion by water pressure on a weakened eggshell and the ability to extend the foot across the diameter of the egg.

Aposematism—the linkage of a conspicuous warning (such as coloration) with a penalty (such as unpalatability) against predation—must be an effective mechanism for protecting the large yolky eggs of the Florida applesnail from terrestrial predators (Snyder and Snyder, 1971; Romer, 1972; Orians and Janzen, 1974), for most claims of predation on its eggs are poorly documented (Bailey, 1925; Blatchley, 1932; Ligas *in* Snyder and Snyder, 1971; Abreu, 1976; Kushlan, 1978). There seems to be general agreement in the literature on applesnails that the major selective pressure for aerial deposition of clutches was the presence of aquatic predators. It seems unlikely, however, that aposematism would have evolved prior to or parallel with aerial oviposition, for aposematism might have been equally as effective against aquatic vertebrates in the past as it appears to be against terrestrial predators today. Indeed, some potential aquatic predators reject eggs offered to them (Snyder and Snyder, 1971).

Other advantages to depositing aerial clutches might be the more favorable incubation temperature and oxygen concentration for embryogenesis; the production of larger hatchlings from larger eggs that could survive only in a well-oxygenated environment; avoidance of mechanical damage from drift material in a high-density medium and from clumsy adults climbing stems to breathe at the surface; avoidance of clutch cannibalism; reduction of microbial growth by exposure of the eggshell to ultraviolet light. None of these possibilities has been studied, although mechanical damage from drift material is implicated in some results from fieldwork of the present study. Oxygen concentration might be a critical factor, for diurnal and seasonal maxima and minima of dissolved oxygen (DO) can differ up to 5–80-fold in marshes and sloughs that hold populations of the Florida applesnail (Belanger et al., 1985; Platko, 1986; Browder et al., 1994). In the present study, DO was not monitored during submergence in the laboratory, but the ratio of water volume to clutch volume was kept high (150:1). Diurnal DO curves are not available for BCWMA East (Snyder, 1997) and Clear Lake.

Whatever the selective pressures might have been for evolution of aerial deposition of clutches, the eggs of the Florida applesnail are now intolerant of submergence, perhaps because of reduced permeability of a calcareous eggshell. Embryos apparently die from physiological stress or other factors before they are eaten by predators. Damage incurred by experimentally submerged clutches in Clear Lake and BCWMA East marsh was low and could not be specifically attributed to predation; other factors easily accounted for shell breakage and loss: hatching, weakened adhesion to stems, impact of or snagging by waterborne debris, impact from adjacent moving stems, and unknown factors that also caused damage to companion aerial clutches.

The potential for submergence by rising waters and for loss of eggs and embryos to predation or other factors probably varies widely according to age of the clutch. Jellied clutches are easily dislodged from their attachment to stems upon submergence. Jellied clutches are, however, the least likely stage in a stand of clutches to be submerged because of the height to which water level must rise in the several hours between oviposition and the desiccation of extracapsular mucus. Early stages in embryogenesis of the Florida applesnail also are the most unpalatable (Snyder and Snyder, 1971; Romer, 1972) but have the least physiological tolerance to submergence. Late-stage embryos, on the other hand, are most prone to submergence by flooding unless they are attached to a vigorously growing plant stem: Water level could rise above clutch height during the 2-wk incubation period. Moreover, unpalatability diminishes as embryogenesis proceeds (Romer, 1972), and late-stage embryos are the most likely to survive submergence physiologically and to hatch under water. Submergence of clutches with late-stage embryos might increase hatchling mortality due to predation. Snyder and Snyder (1971) speculated that bluegill sunfish eat juvenile applesnails in the field as the fish did in laboratory studies. Jaynes (1993) has repeatedly observed sunfish lying in wait beneath clutch-bearing stems in Hunter's Lake, Hernando County, Florida, and consuming hatchling snails as they fall through the water column. Hatching might be the only stage at which submerged clutches experience substantial predation. Predation on hatchlings, whether from submerged or aerial clutches, warrants further study.

The warning of Ryder (1889) must be heeded: submergence of applesnail clutches kills them. Hanning's (1979) determination of the reproductive season from March through October in Lake Okeechobee also seems to hold for BCWMA East and Clear Lake. The potential impact of increases in water level during this season depends upon the distribution of clutch elevations. The distribution that exists at any time reflects recent hydrologic history: If water level is declining, younger, physiologically more sensitive clutches would occupy a lower broad zone on stems, and a greater proportion of them than older clutches would be submerged by subsequently rising waters; if water level is steadily rising, cohorts of older, less sensitive clutches would be submerged in succession. Only clutches nearest to hatching would provide some hatchlings during a period of rapidly rising water. If water level were to increase too rapidly, as much as 2 wk of clutch production in the area would be lost. Production during the first few months of oviposition is probably most critical, for there is evidence that snails hatching early in the year provide the spawning population for the autumn and following spring (Martin, 1973; Hurdle, 1974; Hanning, 1979). In general, however, the biological significance of lost clutches is unknown, for the population dynamics of the Florida applesnail have been little studied.

The distribution of clutch cohorts should be monitored and applied to a dynamic model that could be developed to predict mortality at known or desired rates of flooding. The challenge to effective management is the decision on what level of mortality to accept, considering other priorities in wetlands management. Monitoring water levels will be critical for long-term maintenance of snail populations as a food supply for the snail kite and other predators. Predation on submerged clutches, at least, need not be a consideration.

ACKNOWLEDGMENTS—The following present and former students at Florida Institute of Technology (FIT) assisted with the laboratory and field studies: Kerrie A. Fallon, Jennifer O. Kahrs, Matthew L. Kinter, Michael G. Shlepr, Philip C. Tallon, William D. Turner. The manuscript benefited from reviews by Mary Ann Lee and Edgar F. Lowe of St. Johns River Water Management District (SJRWMD), John H. Dearborn of University of Maine, and Julianne M. Liesman of FIT. The statistical advice of Timothy C. Tricas (FIT) is greatly appreciated. This study was conducted under contract 91D192 with SJRWMD, support from which is appreciated. Information in this paper does not necessarily represent the official District position on this subject matter.

LITERATURE CITED

ABREU, V. 1976. Snails of wilderness waters. Of Sea Shore 7:161–162.

BAILEY, H. H. 1925. The Birds of Florida. The Williams & Wilkins Co., Baltimore, MD. 146 pp.

BELANGER, T. V., F. E. DIERBERG, AND J. ROBERTS. 1985. Dissolved oxygen concentrations in Florida's humic-colored waters and water quality standard implications. Florida Scient. 48:107–119.

BLATCHLEY, W. S. 1932. In Days Agone: Notes on the Fauna and Flora of Subtropical Florida in the Days when Most of Its Area Was a Primeval Wilderness. The Nature Publishing Co., Indianapolis, IN. 338 pp.

BROWDER, J. A., P. J. GLEASON, AND D. R. SWIFT. 1994. Periphyton in the Everglades: spatial variation, environmental correlates, and ecological implications. Pp. 379–418. *In*: DAVIS, S. M. AND J. C. OGDEN, eds. Everglades: the Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, FL.

CHABLE, A. C. 1947. A study of the food habits and ecological relationships of the sunfishes of northern Florida. M.S. Thesis, University of Florida, Gainesville, FL. 98 pp.

DALL, W. H. 1892. Contributions to the Tertiary fauna of Florida, with especial reference to the Miocene Silex-beds of Tampa and the Pliocene beds of the Caloosahatchie River. Part II. Streptodont and other gastropods, concluded. Trans. Wagner Free Inst. Sci. Philadelphia 3:201–473.

DALRYMPLE, G. H. 1977. Intraspecific variation in the cranial feeding mechanism of turtles of the genus *Trionyx* (Reptilia, Testudines, Trionychidae). J. Herpetol. 11:255–285.

DINEEN, J. W. 1974. The fishes of the Everglades. Pp. 375–385 *In*: P. J. GLEASON, ed. Environments of South Florida: Present and Past. Miami Geological Society Memoir 2. Miami Geological Society, Miami, FL.

HANNING, G. W. 1979. Aspects of reproduction in *Pomacea paludosa* (Mesogastropoda: Pilidae). M.S. Thesis, Florida State Univ., Tallahassee, FL. 138 pp.

HENDERSON, J. 1935. Fossil non-marine Mollusca of North America. Geol. Soc. Am. Spec. Pap. no. 3. 313 pp.

HEPLER, N. M. 1974. Report on *Pomacea paludosa*. Deerfield Beach, FL. 17 pp. (Unpublished.)

HOERLE, S. E. 1970. Mollusca of the "Glades" unit of southern Florida: Part II. List of molluscan species from the Belle Glade Rock Pit, Palm Beach County, Florida. Tulane Stud. Geol. Paleontol. 8(2):56–68.

HURDLE, M. T. 1973. Habitat requirements of the apple snail (*Pomacea paludosa*) at Lake Woodruff National Wildlife Refuge. Refuge Management Study Progress Report 2. Lake Woodruff National Wildlife Refuge, DeLeon Springs, FL. 20 pp. (Unpublished.)

———. 1974. Habitat requirements of the apple snail (*Pomacea paludosa*) at Lake Woodruff National Wildlife Refuge. Refuge Management Study Progress Report 3. Lake Woodruff National Wildlife Refuge, DeLeon Springs, FL. 15 pp. (Unpublished.)

JAYNES, N. 1993. Spring Hill, FL, Pers. Commun.

KUSHLAN, J. A. 1978. Predation on apple snail eggs (*Pomacea*). Nautilus 92:57–58.

MARTIN, T. W. 1973. Management for the Everglade kite (*Rostrhamus sociabilis plumbeus*). Refuge Management Study Progress Report 2. (Exclusive of Appendix A mentioned on p. 16.) Loxahatchee National Wildlife Refuge, Delray Beach, FL. 57 pp. (Unpublished.)

MCGINTY, T. L. 1970. Mollusca of the "Glades" unit of southern Florida: Part I. Introduction and observations. Tulane Stud. Geol. Paleontol. 8(2):53–56.

MICHELSON, E. H. 1955. Studies on the biology of the genus *Ceratodes* (Mollusca: Pilidae). Ph.D. Dissertation, Harvard University, Cambridge, MA. 171 pp.

ORIANS, G. H. AND D. H. JANZEN. 1974. Why are embryos so tasty? Am. Nat. 108:581–592.

PAULINYI, H. M. AND E. PAULINI. 1972. Laboratory observations on the biological control of *Biomphalaria glabrata* by a species of *Pomacea* (Ampullariidae). Bull. World Health Org. 46:243–247.

PERERA, G. AND J. G. WALLS. 1996. Apple Snails in the Aquarium. T.F.H. Publications, Inc., Lanham, MD. 121 pp.

PETUCH, E. J. 1992. The Edge of the Fossil Sea: Life along the Shores of Prehistoric Florida. Bailey-Matthews Shell Museum, Sanibel Island, FL. 80 pp.

PLATKO, J. R. 1986. Dissolved oxygen budgets of the Florida Everglades. M.S. Thesis, Florida Institute of Technology, Melbourne, FL. 122 pp.

ROBINS, C. H. 1971. Ecology of the introduced snail, *Marisa cornuarietis* (Ampullariidae) in Dade County, Florida. Biologist 53:136–152.

ROMER, A. J., JR. 1972. The aposomatic [*sic*] eggs of *Pomacea paludosa* (Say). M.S. Thesis, University of South Florida, Tampa, FL. 44 pp.

RYDER, J. A. 1889. Notes on the development of *Ampullaria depressa,* Say. Am. Nat. 23:735–737.

SMITH, M. 1937. East Coast Marine Shells: Descriptions of Shore Mollusks Together with Many Living below Tide Mark, from Maine to Texas Inclusive, Especially Florida. Edwards Brothers, Ann Arbor, MI. 308 pp.

SNYDER, K. L. 1997. St. Johns River Water Management District, Melbourne, FL, Pers. Commun.

SNYDER, N. F. R. AND H. A. SNYDER. 1971. Defenses of the Florida apple snail *Pomacea paludosa.* Behaviour 40:175–215.

TAYLOR, D. W. 1966. Summary of North American Blancan nonmarine mollusks. Malacologia 4:1–172.

THOMPSON, F. G. 1984. The Freshwater Snails of Florida: A Manual for Identification. University of Florida Press, Gainesville, FL. 94 pp.

TUCKER, H. I. AND D. WILSON. 1932. A list of Caloosahatchie Pliocene species. Proc. Indiana Acad. Sci. 41:355–356.

TURNER, R. L. 1996. Use of stems of emergent plants for oviposition by the Florida applesnail, *Pomacea paludosa,* and implications for marsh management. Florida Scient. 59:34–49.

——— AND C. M. MCCABE. 1990. Calcium source for protoconch formation in the Florida apple snail, *Pomacea paludosa* (Prosobranchia: Pilidae): more evidence for physiologic plasticity in the evolution of terrestrial eggs. Veliger 33:185–189.

WALLACE, H. E., C. M. LOVELESS, F. J. LIGAS, AND J. A. POWELL. 1956. Wildlife investigation of the central and southern Florida flood control project. Annual progress report for Investigations Project as required by Federal Aid in Fish and Wildlife Restoration Acts. Florida Game and Fresh Water Fish Commission, Tallahassee, FL. 36 pp. (Unpublished.)

WILBUR, R. L. 1969. The redear sunfish in Florida. Florida Game and Fresh Water Fish Commission Fish. Bull. 5. Florida Game and Fresh Water Fish Commission, Tallahassee, FL. 64 pp.

Florida Scient. 61(2): 118–129. 1998
Accepted: October 22, 1997

SINGLE NODE AQUIFER ANALYSIS—A WATER-BUDGET MODEL

R. P. HAVILAND

MiniLab Instruments, P.O. Box 211086, Daytona Beach, FL 32121

ABSTRACT: *Describes the concept and approach of a water budget computer model which treats an entire aquifer as a unit, with emphasis on long-term effects. The model includes terms for rainfall, runoff, evapotranspiration, recharge/discharge, leakage, springs and pumpage, and allows multiple aquifer layers. The paper shows an example of application of the model to a real-world aquifer of reasonably well known characteristics.*

A TYPICAL practice in aquifer analysis is to use a ground-water model, and to seek increased detail by increasing the number of nodes in the potentiometric network scheme (Prickett and Lonnquist, 1971; McDonald and Harbaugh, 1988). The program approach described here treats the aquifer as a single entity, rather than a collection of a large number of nodes. The quantity of water stored in the aquifer is related to the other events and phenomena involved in the total water system. For the model described this includes explicit consideration of rainfall, evaporation, runoff, evapotranspiration, springs, swamps and lakes, water in storage and consumption, plus indirect consideration of drainage canals and impervious surfaces. Fig. 1 shows these main elements schematically.

METHODS—A functioning model cannot be prepared without consideration of the physical world. The computer model is written with set of parameters which can be varied to suit the aquifer, or to correct assumed parameter values when the model results do not agree with calibration trials. This has the advantage of allowing "what if" analysis, important as aquifer exploitation increases or if corrective actions are to be tried. The model is written in module form, to allow deletion or addition of routines. For example, extension to multiple nodes requires changing dimensions of some variables, and addition of a routine to calculate inter-node flow.

The physical aquifer—The example aquifer used here is the 1500 square mile Volusia-Flagler Sole Source Aquifer of east central Florida, as designated by the EPA (EPA, 1987): this includes essentially 100% of Volusia county, 30% of Flagler county and a small part of Putnam county, Florida. The main parts of the aquifer complex (Rutledge, 1984; Geraghty and Miller, 1991) include a tilted limestone block, defined by a fault essentially at the St. Johns River to the west. The block top is near sea level at the west, and at about −100 feet at the ocean 30 miles to the east. The aquifer extends under the ocean an unknown distance: the predevelopment potentiometric level was well above sea level at the coast (wells close to the coast showing partial diurnal tidal amplitude changes in level). The limestone block is effectively divided into layers by dolomitic deposits, the major one being about 100 feet below the top, defining the upper and lower Floridan aquifer. The limestone is overlain by a relatively

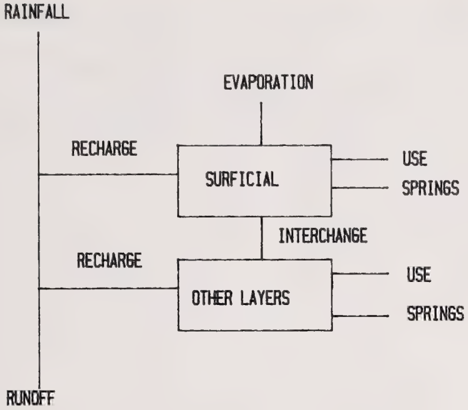


FIG. 1. Simplified schematic of the major elements for aquifer analysis using the water-budget approach. The aquifer modeled here extends this basic model to three levels, with use from all levels and springs from two. Relations amongst quantities are given in the text.

impermeable clay layer in most places, then by sand and shells with occasional clay lenses, this forming the surficial aquifer.

Just to the east of the St. Johns River is the DeLand ridge, a fossil sand dune averaging about +60 feet elevation. There are several hundred sinkholes on the ridge (early Karst type), with no runoff from most of the ridge (Rutledge, 1984). There are also lakes, some definitely sinkhole associated, some connected to the aquifer by bottom springs, and some perched, as shown by elevations as compared to the local surficial potentiometric level. To the east of the ridge is the Talbot Terrace, a poorly drained old sea bed at about +40 feet, with extensive swamps. Elevation decreases to the east in a series of ridges and terraces. The north and south boundaries appear to be diffuse, with some lowering of surface and subsurface layer elevations, with indication of multiple faults plus reduction in permeability. The local system is effectively separated from the Floridan aquifer of the rest of the State by the combination of faults, elevations and recharge sources, the justification for the Sole-Source designation.

The surface layers are pumped for lawn irrigation, and for some home use. The municipal systems pump the upper Floridan, which has good yield and low dissolved solids. This is also used by industry and agriculture. There is some use of the lower Floridan, which has higher dissolved solids, and variable yield characteristics.

Model representation—Model relations follow customary equations, with a few additions or special extensions. Because of the surface elevation and fault patterns, the only input to the example system is rainfall, to a good approximation. The records of the US Weather Service, Daytona Beach, show that this is variable from 30 to 80 inches per year in an extreme-value distribution. There is a seasonal variation, which can be represented by a 7 month dry season with 2 inches/month, and a 5 month wet season of 7 in/mo. Variations in rainfall are simulated by using random functions, independent for the wet and dry seasons. Table lookup could be used for historic rain, but is not currently in the model.

While the three aquifer layers typically have different potentiometric levels, rainfall and variations in the three potentiometric levels are often highly correlated. An interpretation is that rainfall can reach the layers directly via sinkholes, as well as by vertical interchange between layers. In the model the rainfall fraction fed to each layer, and the direct runoff fraction can be varied, the sum of the four coefficients equalling unity. The model assumes also that a water reuse program can be included, and that it acts as an increase in rainfall. Inter-layer flow parameters were obtained by graphical integration of recharge charts (Rutledge, 1984).

There are four major springs to the west of the DeLand ridge. The largest appears to be fault associated, and fed from the lower Floridan. This flow is assumed to be approximated by flow in a filled channel. The other springs appear to be fed from the Upper Floridan, with some evidence of conduit flow, based on verbal reports of divers entering the boil. Since one spring has become intermittent as the potentiometric has fallen, and another projects to zero average flow in the next 25 years, these flows are assumed to be linear above a threshold potentiometric. All flows go to zero if the term becomes negative.

Before development there were many seeps on both the west and east sides of the County, apparently from the surficial. These are combined with a runoff term, set to occur if the surficial potentiometric rises above the land surface. Holding time by swamps and streams is simulated by assigning a fraction escaping as runoff in 30 days. The evaporation from free water is assumed to be 50 inches per year, independent of season. When the potentiometric level is lower than the surface, the evapotranspiration is assumed to be a fourth power of the drop, which causes the evaporation to decrease rapidly as the water table falls.

Pumpage from the layers can be independently set. At present, an assigned growth rate is assumed to apply to all layer pumpage. At this time, there is no explicit provision for growth of impervious surfaces with time, or for drainage canals or reuse. These quantities can be simulated by adjustment of a corresponding factor, for example, the direct rain runoff parameter for impervious surface change.

For analysis, the surficial and upper Floridan upper are assumed to occupy the entire aquifer area with constant thickness. The lower Floridan is assumed to occupy the same area: however, for calculation purposes, the thickness of the zone is assumed to vary with its potentiometric level: in essence, this assumes the formation of a bubble of fresh water floating over salt water.

The amount of water in each layer is based on its potentiometric level and storage coefficient, area and thickness. Simple addition of the input and output terms is used to determine the change in water quantity in the calculation interval, one month.

The program is written in BASIC, and has been translated into spreadsheet form. [Copies of the program in spreadsheet form can be obtained from the author. Include a 3 ½ inch disk and a stamped mailer with a request.]

RESULTS—Graphical results of a simulation run, using default values, a 10% annual growth in pumpage and variable rainfall are shown (Fig. 2). Some variation for the first 5 years in this shows that the assumed initial values do not correspond exactly to the equilibrium point of the defined system. Inspection of results shows that the effect of pumpage growth can be seen after 10–15 years, and that the growth is having marked effect at 30–35 years. The effects tend to be disguised by the presence of variable rainfall.

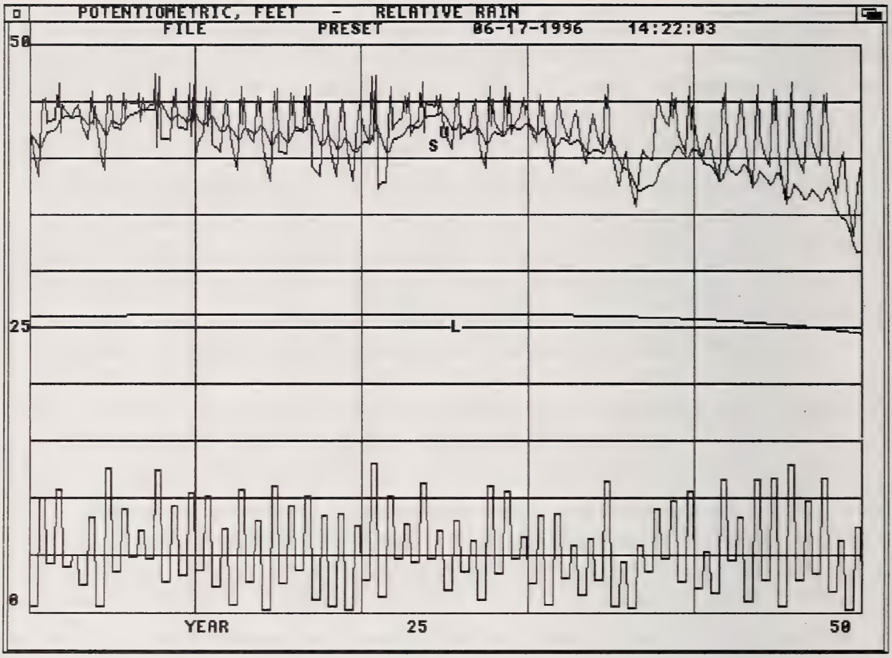
It is much easier to see what is happening by allowing only one change variable at a time (Fig. 3, for growth variation only). All aquifer layers show decreased potentiometric after 20–25 years. Recharge does increase, but this is at the expense of evaporation and runoff; by 45 years, these are a fraction of the pre-development values, even in the wet season. The assumed growth conditions are leading to desertification, with resulting major modification to the native vegetation of the area modeled.

Some study of methods of alleviating the effects of increased pumpage have been made using this simple model. Returning used water to the surficial aquifer does reduce the amount of decrease of the surficial and upper Floridan potentiometric, and helps maintain runoff and evaporation. However, it should be noted that present water reuse programs in the model area cannot attain the calculated degree of improvement. The large consumption east coast cities instituted "reuse" in response to mandates to eliminate sewage plant effluent from their adjacent estuarial waters. The chosen points of application of the bulk of reuse water (golf courses, road/street media, lawns) is on terrain too near sea level to provide recharge to the limestone layers. The same factor means that there is little value in maintaining stream flow, except locally. There does exist a conceptual approach involving pumpage to the Talbot terrace, which would improve recharge and stream flow, but no action has been taken on this possibility.

The present method of simulating canals is by change in surface elevation. There is indication from such runs that the present canals are increasing runoff and reducing evaporation: this corresponds to reports of the County Forester that swamp drying and intrusion of dry footed species into formerly swampy areas is being observed. The computer runs show that recharge is also affected, and that a program of canal flow control should increase recharge. The amount or recharge possible should increase with time, since the canals largely drain the terraces, which become recharge areas when the aquifer potentiometric is low. Full evaluation of this will require a multi-node analysis, where the differences in surface elevation can be modelled. This change is apparently also necessary for full simulation of spring flow.

Table 1 shows model results considered as a water budget indicator. The current consumption approaches 150 mgd. The effects predicted by the model are currently noticeable, as vegetation modification in the terraces, low stream flow and surface water quality problems.

Comparison with other results—No equivalent studies of the general problem are known to the author. All found focus on short term effects. For example, Zhang and Landstrom (1996) compares two models, but for periods of less than a year, with primary emphasis on runoff. The emulation terms are more complex and presumably more accurate than those here, but important long term effects are not included. Saltwater intrusion studies of the model aquifer are available (Geraghty and Miller, 1991) as are surface water quantity and quality models (Suphunvorranop and Tai, 1982). The closest study for the example sole-source aquifer is Kinser and Minno (1995), which is based on estimation of the drawdown of the surficial aquifer by pumpage of the upper Floridan zone, as calculated by conventional multinode analysis. This plus Annable and co-workers (1996) show that increasing attention is being given to coupling of the aquifer itself to other elements of the total water system. A further example of this is German (1997) which explicitly models the evaporation and water levels of wetlands. However, while giving a good correlation to measured levels, this model is based on historic values of rainfall, and does not consider the effects of pumpage of


POTENTIOMETRIC, FEET - RELATIVE RAIN
FILE PRESET 06-17-1996 14:22:03
50
25
0
S
U
L
YEAR
25
50

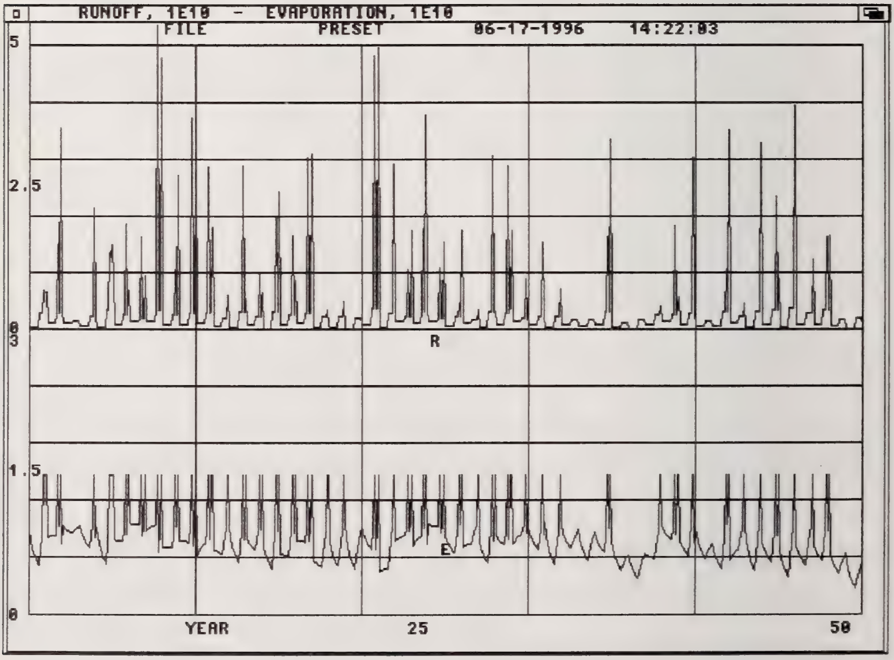

RUNOFF, 1E10 - EVAPORATION, 1E10
FILE PRESET 06-17-1996 14:22:03
5
2.5
0
3
1.5
0
R
E
YEAR
25
50

FIG. 2. Three of the four visual output screens generated by the program on a expanded Amiga workstation, each with several related quantities in graphical form. The top line gives the quantities plotted, the second the file name and scale multiplier plus date and time of the

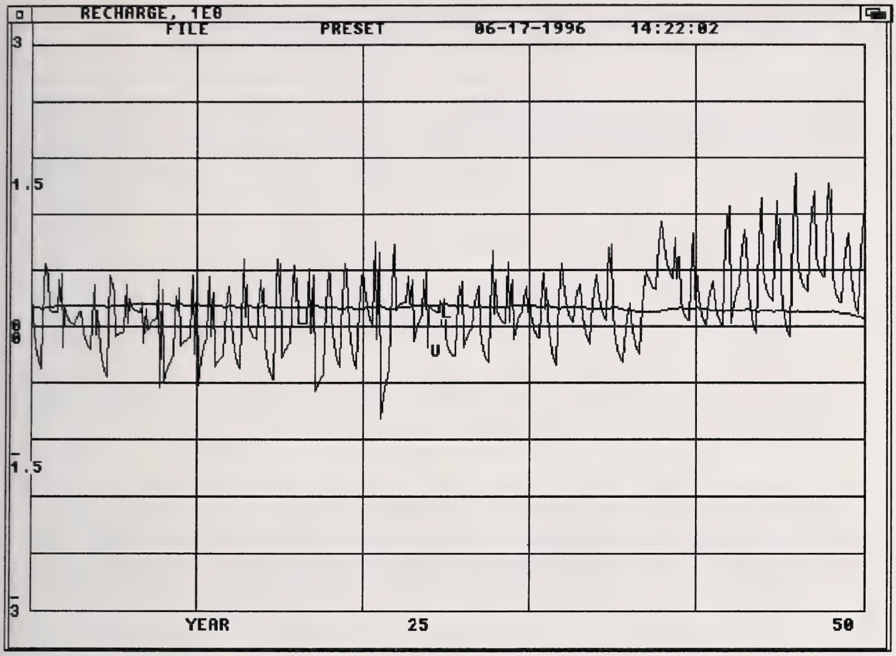


FIG. 2. Continued.

the aquifer levels; in its current form, it is suited to short term studies rather than long term predictions.

If rainfall and monitoring well levels are maintained in spreadsheet form, one independent evaluation is simple. For a reasonable period, say five years, a plot of monthly well level change from the previous month versus the rainfall in that month is prepared, and the best fit line determined. Because of the many variables present, the data will show much scatter in the plot. However, the rainfall corresponding to zero level change is an estimate of the average monthly rainfall required to maintain the level of that well. Repeating for several wells and several time periods will give a reasonable estimate of aquifer health. For the example aquifer, and for a monitoring well remote from all pumpage, over the period 1990–1995, this method indicates that rainfall of 5.0 ± 1.3 inches per month is needed to maintain

---

←

analysis. Units are on the left axis. (a) The three potentiometric levels in feet and the monthly rainfall in inches. (b) The runoff and evaporation. (c) Recharge, surficial to upper and upper to lower Floridan. (The fourth screen is for usage from the three layers, and spring flow). The great variability in runoff and evaporation is partly a result of the time intervals used for these graphs to give reasonable plotting speed: shorter intervals give a lower peak value for the same total amount of water.

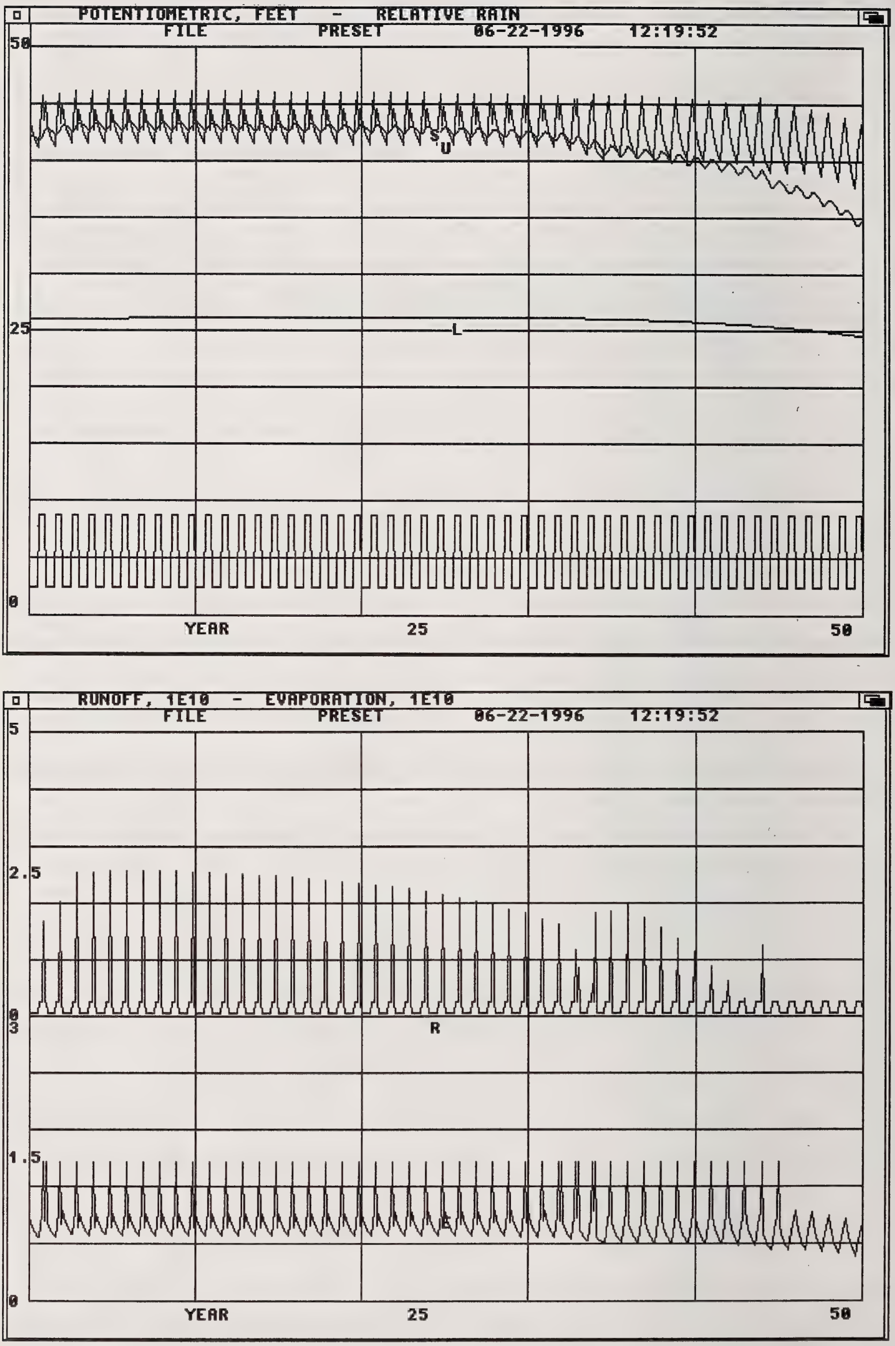


FIG. 3. Plot for same parameters as Fig. 2 a and b, but with the rain randomizing functions inactive. The effect of increased consumption is now very visible. While recharge does increase as the aquifer level falls, this is at the expense of reduced runoff and lower evaporation.

TABLE 1. Water budget indications based on model results. The general trend of the effects of a given amount of consumptive use pumpage is given in the effect column.

Pumpage, 1E6 gal/day	Effect on Aquifer
15	Small to negligible effect
40	Just noticeable effects
150	Reduction in runoff, evaporation, falling potentiometric levels
225	Marked reductions, small dry season stream flow, start of desertification

the aquifer level. Since the area rainfall averages 4.25 inches/month, this simple test indicates that the model finding of aquifer drawdown is probably correct.

CONCLUSION—This simple approach neglects a number of important factors, such as salt water intrusion, terrain subsistence and soil compaction due to pumping, and impact on estuaries, and must rely on approximations for others. It is not a sufficient basis for making major decisions about the water system which includes the aquifer. But the same situation exists for other analysis methods: even those calculating saltwater intrusion neglect terrain modification, vegetation changes and impact on streams and estuaries. All have ignored the impact of drainage canals. The approach here appears to be a worthwhile technique addition where corrective steps are needed and an overview of the results of "what if we try this" will be helpful.

The model shows that it is necessary to consider all parts of the water system when evaluating the effects of growth in water usage. For the example sole-source system a large quantity of water remains in reserve, even at the end of the 50 year study period. However, this Lower Floridan water is of lower quality, and its use will increase costs. The drawdown of the Upper Floridan is the primary factor in the indication of major vegetation and stream changes resulting from increased use.

At 10% growth rate, the consumption doubling time is almost exactly 7 years. Considering the time required to develop, fund and implement corrective actions, this simplified model indicates that time is becoming critical for this sole-source aquifer.

LITERATURE CITED

ANNABLE, M. D., L. H. MOTZ, AND W. D. BEDLOW. 1996. Investigation of Lake and Surficial Aquifer Interaction in the Upper Etonia Creek Basin: Interim Report, SJWMD Special Publ. SJ96-SP14. Palatka, FL.

ENVIRONMENTAL PROTECTION AGENCY. 1987. EPA Fact Sheet, Volusia Floridan Sole Source Aquifer. Atlanta, Nov. 6.

GERAGHTY AND MILLER, INC. 1991. Numerical Modelling of Ground-water Flow and Seawater Intrusion, Volusia County, Florida, Reston, VA.

GERMAN, E. R. 1997. A Method for Evaluating Water-Level Response to Hydrologic Stresses in Karstic Wetlands in Central Florida, Using a Simple Water Balance Model, U. S. Geological Survey WRI Report 96-4216, Tallahassee, FL.

KINSER, P. AND M. C. MINNO. 1991. Estimating the Likelihood of Harm to Native Vegetation from Ground Water Withdrawals, SJWMD Technical Publication SJ95-8, Palatka, FL.

MCDONALD, M. G. AND A. W. HARBAUGH. 1988. A modular three-dimensional finite-difference ground-water model, Techniques of Water-Resources Investigations, Book 6, Chapter A1, USGS, Reston, VA.

PRICKETT, T. A. AND C. G. LONNQUIST. 1971. Selected Computer Techniques for Groundwater Resource Evaluation, Illinois State Water Survey Bulletin 55, Urbana, IL.

RUTLEDGE, A. T. 1984. Ground-water hydrology of Volusia County, Florida, USGS WRI Report 84-4206, Talahassee, FL.

SUPHUNVORRANOP, T. AND C. C. TAI. 1982. Upper St. Johns Hydrologic Model Users Manual, SJWMD technical Report 15, Palatka, FL.

ZHANG, X. AND G. LANDSTROM. 1996. A Comparative Study of a Swedish and a Chinese Hydrological Model, American Water Resources Association Bull., 32, 5, Oct.

Florida Scient. 61(2): 130–138. 1998
Accepted: October 22, 1997

REVIEW

Anthony F. Randazzo and Douglas S. Jones (Eds.). *The Geology of Florida*, University Press of Florida, Gainesville, FL, 1997. Pp. xviii + 327. Price, $39.95, clothbound.

As the first comprehensive compilation of Florida's Geology since the last such publication by Puri and Vernon, 1964, the editors have assembled a stellar group of authors to update the earlier publications by including the results of their research and that of others in fourteen informative chapters. Since the publication by Puri and Vernon, developments in the understanding of Geology have significantly helped to understand Florida's Geology. Much of this new information is the result of graduate student theses and faculty's research that has focused on interpreting surficial, sub-surface and geophysical data. Acceptance of the theory of Continental Drift has opened the door to explanations of such Florida enigmas as the presence of upturned igneous and metamorphic rocks in Cuba a scant few miles south of Key West where thousands of feet of horizontal rocks are present. In addition, one now has a much better understanding of the origin of the Sigsbee Deep as well as well as the scarp along the western edge of Florida's continental shelf.

One of Florida's most troubling future problems will be the availability of fresh water for human, industry and agriculture consumption. Unfortunately, the chapter on Hydrogeology of Florida is dated by between 8 and 10 years and does precious little to alert the reader to the pending crisis caused by population concentration, consumption rates, salt water intrusion and contamination of Florida's fresh water resources.

Anyone who is seriously interested in any aspect of Florida's Geology will have this outstanding book in their library as a starting point for their investigation. The bibliographic references and index are excellent as are the illustrations.—William H. Taft, Instituite for Environmental Studies, University of South Florida, Tampa, FL.

REVIEW

Heinz K. Henisch, *Crystal Growth in Gels,* Dover, Mineola, NY, 1996 (reprint). Pp. 112 $7.95 (paperbd).

THIS book can be read at two levels, one for the expert, and one for the amateur. It is the answer to queries that I have commonly received: how do you grow crsytals? The approach described here grows crystals in a gel medium. The complexity of the apparatus ranges from simple test tubes to U–shaped tubes to a double diffusion system with reservoirs that would be readily prepared by a qualified glassblower. The general background is a model of clear writing. In addition, the author presents clear, effective directions for preparing the crystals in different gel media. Also, directions for so-called Liesegang rings are given for silver chromate and calcium phosphate. Physical scientists will find the book attractive, but so will teachers and their students.—Dean F. Martin, IES, Department of Chemistry, University of South Florida, Tampa, FL 33620.

INSTRUCTION TO AUTHORS

Individuals who wish to publish in the *Florida Scientist* must be active members in the Florida Academy of Sciences.

Submit a typewritten original and two copies of the text, illustrations, and tables to the editors. All typewritten material–including the abstract, literature citations, footnotes, tables, and figure legends–shall be double-spaced. Use one side of 8½ × 11 inch (21½ cm × 28 cm) good quality bond paper for the original; the copy may be xeroxed. Margins should be at least 3 cm all around. Number the pages through the Literature Cited section. Avoid footnotes and do not use mimeo, slick, erasable, or ruled paper. Use metric units for all measurements. *Papers in excess of 10 pages by an author in a single volume will result in page charges ($57 per page) for the excess pages.*

Address follows the author's name.

Abstract–all manuscripts shall have a short, concise, single-paragraphed abstract. The abstract follows immediately the author's address.

Acknowledgments are given in the body of the text preceding immediately the Literature Cited section.

Literature Cited section follows the text. Double-space every line and follow the format in the current issue.

Manuscripts of 5 or less, double-spaced typewritten pages should conform to the short article protocol. See recent issue for proper format of both long and short articles.

Tables shall be typed on separate sheets of paper, double-spaced throughout. Each table shall contain a short heading. Do not use vertical rulings. Maximum character width, including spaces, of tables is 98.0. This includes a minimum space of 5 characters between columns.

Illustrations–All drawings shall be done in good quality India ink, on good board or drafting paper. Letter by using a lettering guide or equivalent. Typewritten letters on illustrations are unacceptable. Drawings and photographs should be large enough to allow ⅓ to ½ reduction in size. Photographs shall be glossy prints of good contrast. Whenever possible, mount photographs in lots size.

The author's name and figure number should be penciled lightly on the back of each figure. Figure legends must be listed on a separate page and not on the drawing or photograph. The legend must be double spaced. Illustrations are charged to authors at $16.00 for halftones and $11.00 for line art.

We ask authors to prepare accepted manuscripts in personal computer formats. **Please do not submit a manuscript on disk.** Once reviewers have recommended a manuscript be accepted, you will be given directions for submitting the **final manuscript on disk.**

Proof must be returned promptly. Notification of address change and proofreading are the author's responsibility. Alterations after the type has been set will be charged to the author.

Reprints may be ordered through the Business Manager from the printer on forms provided at the time that proofs are sent to authors for checking.

FLORIDA ACADEMY OF SCIENCES

Institutional Members for 1998

Brevard Community College, Palm Bay
The British Library, Boston Spa, Weatherby, UK
The British Library, RAS Washington DC Professional Campus
Cleveland Public Library, Cleveland, OH
Edison Community College
Florida International University
Harbor Branch Oceanographic Institution, Inc.
Long Island University
Museums Library, University of Michigan
Orlando Science Center
St. Petersburg (FL) Junior College
St. Thomas University
St. Thomas University Library
Saint Petersburg Public Library
Science Library, University of Chicago
University of Miami
University of North Carolina at Wilmington

Membership applications, subscriptions, renewals, and changes of address should be addressed to the Executive Secretary, Florida Academy of Sciences, Orlando Science Center, 777 Princeton St., Orlando, FL 32803.

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 University Blvd., Melbourne, FL 32901-6975 [(407) 768-8000, ext. 8196; e-mail rturner@fit.edu].

PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Prices quoted include domestic postage. Some issues may not be available. All are $20 per volume or $5 per issue, except for symposium issues.

Proceedings of the Florida Academy of Sciences (1936–1944)
  Volumes 1–7
Quarterly Journal of the Florida Academy of Science (1945–1972)
  Volumes 8–35
Florida Scientist (1973–)
Florida's Estuaries—Management or Mismanagement?—Academy Symposium
  Florida Scientist 37(4)–$5.00
Land Spreading of Secondary Effluent—Academy Symposium
  Florida Scientist 38(4)—$5.00
Solar Energy—Academy Symposium
  Florida Scientist 39(3)—$5.00 (includes do-it-yourself instructions)
Anthropology—Academy Symposium
  Florida Scientist 43(3)—$7.50
Shark Biology—Academy Symposium
  Florida Scientist 45(1)—$8.00
Future of the Indian River System—Academy Symposium
  Florida Scientist 46(3/4)—$15.00
Second Indian River Research Symposium—Academy Symposium
  Florida Scientist 53(3)—$15.00

Please send payment with order. If required, an invoice will be sent on purchases over $20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.

11
F6F63
NH

ISSN: 0098-4590

W

Florida Scientist

FLORIDA ACADEMY of SCIENCES
1936

Volume 61 Summer/Autumn, 1998 Number 3/4

CONTENTS

Herpetofaunal Survey of an Upland Hardwood Forest in Gadsen County, Florida ..... Kevin M. Enge 141
Status and Conservation of Southeastern Myotis Maternity Colonies in Florida Caves ..... Jeffrey A. Gore and Julie A. Hovis 160
Acknowledgment of Reviewers 170
Land Use and Land Cover Trends in Florida, 1936–1995 ..... Randy S. Kautz 171
Age and Growth of a Newly Established White Bass Population in Florida ..... Jeffrey J. Nordhaus, Brian R. Lubinski, Richard L. Cailteux, and Daniel A. Dobbins 188
Studies of the Florida Convolvulaceae—VI. *Dichondra* ..... Daniel F. Austin, Sebsebe Demissew, and Jill Young 195
RAPD Analysis of the Last Population of a Likely Florida Keys Endemic Cactus ..... D. R. Gordon and T. L. Kubisiak 203
Florida Medalists 211
Omitted Abstracts 212
Table of Contents, Volume 61 213

SMITHSONIAN
OCT 23 1998
LIBRARIES

FLORIDA SCIENTIST

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Copyright© by the Florida Academy of Sciences, Inc. 1998

Editor: Dr. Dean F. Martin Co-Editor: Mrs. Barbara B. Martin
Institute for Environmental Studies, Department of Chemistry, University of South Florida,
4202 East Fowler Avenue, Tampa, Florida 33620-5250
Phone: (813) 631-4121; e-mail: Martin@chuma.cas.usf.edu

Business Manager: Dr. Richard L. Turner
Department of Biological Sciences, Florida Institute of Technology,
150 West University Boulevard, Melbourne, Florida 32901-6975
Phone: (407) 768-8000, ext. 8196; e-mail: rturner@fit.edu

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at $40.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

Officers for 1998–1999
FLORIDA ACADEMY OF SCIENCES
Founded 1936

President: Mr. Al Hall
City of Tallahassee
4335 Sherborne Road
Tallahassee, FL 32303

President-Elect: Dr. Maribeth Durst
St. Leo College
St. Leo, FL 33574

Secretary: Dr. Richard March
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416

Treasurer: Mrs. Georgina Wharton

Executive Secretary: Ms. Geralyn Heartz
777 East Princeton St.
Orlando, FL 32803
407:896-7151, ext 2079; e-mail:
gheartz@osc.org

Program Chair: TBA

Published by The Florida Academy of Sciences, Inc.
Printing by Allen Press, Lawrence, Kansas

Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Dean F. Martin, *Editor* Barbara B. Martin, *Co-Editor*

Volume 61 Summer, 1998 Number 3/4

Biological Sciences

HERPETOFAUNAL SURVEY OF AN UPLAND HARDWOOD FOREST IN GADSDEN COUNTY, FLORIDA

Kevin M. Enge

Florida Game and Fresh Water Fish Commission, Joe Budd Wildlife Field Office, Route 7,
Box 3055, Quincy, FL 32351

Abstract: *Information is scarce on the herpetofaunal community of upland hardwood forest. Three drift fence arrays were used over a one-year period to survey the herpetofauna of a tract of upland hardwood forest in Gadsden County, Florida. A total of 914 individuals of 18 amphibian and 14 reptile species was captured. Coverboards and incidental observations yielded one additional amphibian and seven additional reptile species. The most frequently captured species were the southern toad (*Bufo terrestris*), three-lined salamander (*Eurycea guttolineata*), southern two-lined salamander (*E. cirrigera*), and southeastern slimy salamander (*Plethodon grobmani*). Recaptures constituted 13.3% of all captures. Reptiles exhibited a bimodal pattern of seasonal activity. Most anurans (95.6%) and reptiles (81.6%) were captured from April to October. Over one-half of the anurans captured were immature individuals. Salamanders exhibited more year-round activity than anurans, particularly during periods of precipitation during their breeding seasons. Bimonthly capture rates for anurans were correlated with lowest recorded minimum air temperature and amount of precipitation, whereas capture rates for salamanders were only correlated with amount of precipitation. Noteworthy findings were the presence of four-toed (*Hemidactylium scutatum*) and Apalachicola dusky (*Desmognathus apalachicolae*) salamanders. Retention of undisturbed hardwood forests along streams and protection of the quantity and quality of water in streams and seepage areas are recommended to maintain a diverse amphibian community in a fragmented rural or residential landscape.*

Information is scarce on the herpetofauna of upland hardwood (i.e., southern hardwood or beech-magnolia) forest, which is often considered the equilibrium "climax" community in the northern panhandle of Florida. However, the composition and structure of this habitat type continually changes over time and space in response to variable local environmental conditions and subtle differences in topography (Platt and Schwartz, 1990), and there apparently are no vertebrates endemic to this community, although it is used by many species (Wolfe et al., 1988). Streams and seeps in upland hardwood forest provide important habitat for several salamander species with restricted distributions in Florida (Wolfe et al., 1988; Means and Karlin, 1989; Means, 1992). Alteration and fragmentation of the habitat for logging and development could negatively affect these salamanders as well as other components of the herpetofaunal community. I conducted a survey using three drift fence arrays for one year in upland hardwood forest with seeps and streams in northeastern Gadsden County, Florida, to determine the herpetofaunal community composition of this dwindling habitat type. From 1970 to 1987, the coverage of upland hardwood forests decreased 27% in Florida (Kautz, 1993).

STUDY AREA—*Location and land use*—The tract of upland hardwood forest surveyed was 1.8 km west of Havana, Gadsden County, Florida (30°37.57′N, 84°25.96′W). The study area was on a 1.8-ha lot that consisted of 66% forest, 21% lawn, and 13% old field, and was situated in a woodland corridor that averaged 300 m wide and extended along a tributary of Salem Branch, which is a tributary of Attapulgus Swamp Creek (part of the Little River watershed in the Ochlockonee River drainage). The land sloped from 64 m above sea level in the cleared portion of the lot to 52 m along the Salem Branch tributary bordering the west side of the lot. A small first-order stream (Strahler [1964] classification), which averaged 70 cm wide and originated ≈150 m upstream along a seepage slope, bisected the woods and flowed into the second-order tributary ≈1.4 km upstream from its confluence with Salem Branch.

Most upland areas in the vicinity had been previously cleared and converted to subdivisions, agricultural land, and ornamental plant nurseries. The cleared upland area on the study site was formerly a shade tobacco farm but now consists of an old field dominated by various grasses, goldenrod (*Solidago* spp.), and blackberry (*Rubus* spp.), and a lawn consisting mostly of bahia grass (*Paspalum notatum*) and numerous weed species. Past land-use history of the forest included some trash dumping and possible livestock use.

Habitat description—The drift fence arrays were situated in upland hardwood forest habitat, part of which was slope forest (Florida Natural Areas Inventory, 1990). Most of the forest had ≈75% canopy cover consisting of southern magnolia (*Magnolia grandiflora*), spruce pine (*Pinus glabra*), American beech (*Fagus grandifolia*), sweetgum (*Liquidambar styraciflua*), swamp chestnut oak (*Quercus michauxii*), water oak (*Q. nigra*), pignut hickory (*Carya glabra*), and ironwood (*Carpinus caroliniana*). The seepage areas were characterized by tulip poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), and sweetbay (*M. virginiana*). The most upland areas contained many of the aforementioned species plus loblolly pine (*Pinus taeda*) and a mid-canopy of hophornbeam (*Ostrya virginiana*), redbud (*Cercis canadensis*), and flowering dogwood (*Cornus florida*). Shrub-cover density was variable, and the predominant species were various canopy species, bluestem palmetto (*Sabal minor*), beautyberry (*Callicarpa americana*), and elderberry (*Sambucus canadensis*). Large muscadine grape (*Vitis rotundifolia*) vines were common. The seepage areas and first-order stream banks typically had a dense cover of ferns, including netted chain (*Woodwardia areolata*), southern lady (*Athyrium filix-femina*), and cinnamon (*Osmunda cinnamomea*) ferns. Other ground cover consisted of Virginia creeper (*Parthenocissus quinquefolia*), dewberry (*Rubus trivialis*), poison ivy (*Rhus radicans*), partridge berry (*Mitchella repens*), jack-in-the-pulpit (*Arisaema triphyllum*), and green dragon (*A. dracontium*). The edge of the woods contained some planted pear and peach trees; various weed species and extensive Japanese honeysuckle (*Lonicera japonica*) extended from the edge to 20 m into the woods.

METHODS—The survey was conducted using drift fences in conjunction with funnel traps in a modified three-fence array design (Jones, 1986). The three arms of the array were constructed of silt fencing (Enge, 1997c) and met at a centerpoint at 120° angles. The total length of fencing per array was ≈22 m, and installed fences were ≈75 cm high. Single-opening funnel traps (86 cm long, 25 cm diameter) were placed on each side at the distal end of each fence, and double-opening funnel traps (86 cm long, 20 cm diameter) were placed ≈2.5 m from the centerpoint on each side of each fence. Funnel traps were constructed of aluminum window screen fastened together with office staples. Moistened sponges were placed in traps to keep small animals from desiccating, and traps were shaded by 41-cm square boards of tempered masonite.

Three arrays were installed in diverse microhabitats in order to maximize the number of species captured. Array 1 was situated in a shallow seepage area of sand and muck that periodically dried up but typically flowed into the first-order stream bisecting the woods. Array 2 was immediately adjacent to the stream, and Array 3 was on a slope near the junction of the first-order stream and the Salem Branch tributary. The distance between the centers of arrays 1 and 2 was 73 m, and the distance between arrays 2 and 3 was 46 m.

Trapping was conducted continuously from 19 June 1994 to 19 June 1995. Traps were checked every two to ten days (average 5.5 days), depending on weather conditions. Traps were checked more frequently during periods of precipitation, especially during warm weather, when large numbers of amphibian captures were anticipated. A stack of two or three sheets of roofing tin (0.65 x ≈3 m) was placed at each of five sites in the old-field habitat and along the edge of the forest. These coverboards were checked sporadically from June 1994 to May 1997 in order to detect additional species present on the site.

All live captures were marked and released ≈3 m away on the opposite side of the fence. Age class and sex of each captured specimen were recorded whenever possible. Breeding condition of salamanders was determined by the presence of gravid females, the development of cirri from the nostrils of male *Eurycea,* and the presence of a mental gland under the chin of male slimy salamanders (*Plethodon grobmani*). All amphibians were marked using the same number. Reptiles were individually numbered except for small snakes, which were not marked.

Precipitation and maximum/minimum air temperature were recorded each time traps were checked. Linear regressions were run using SigmaStat on bimonthly weather variables (total precipitation, highest recorded maximum temperature, and lowest recorded minimum temperature) and capture rates for amphibians and reptiles. Duration of the bimonthly periods ranged from 12–19 days, so daily capture rates were calculated and then multiplied by 15 for standardization purposes (Table 1). Comparisons of capture rates among different studies were conducted using the number of captures array^{-1} day^{-1} (i.e., array-day; Campbell and Christman, 1982; Corn, 1994) x 100 and the number of captures km^{-1} day^{-1} (i.e., km-day; Enge, 1997b), which takes into account differences among studies in the length of fencing used (Table 2).

RESULTS—*Seasonality of captures*—Bimonthly maximum air temperatures ranged from 21°C to 38°C, and bimonthly minimum air temperatures ranged from −5°C to 21°C (Table 1). Bimonthly precipitation ranged from 0 mm to 353 mm, with most precipitation occurring from June through early October (Table 1).

Multiple linear regression indicated a significant correlation between bimonthly reptile capture rates and precipitation, minimum temperature, and maximum temperature ($F = 3.50$, 23 df, $p = 0.03$), but these weather variables accounted for only 25% of the observed variation in reptile capture rates. Reptile capture rates exhibited a bimodal pattern, despite the small sample size. Most reptile captures occurred from late April through June and in September and October, with 45% of all snake captures occurring

TABLE 1. Bimonthly precipitation totals (mm), highest maximum and lowest minimum air temperatures (°C), and herpetofaunal captures per 15-day period in upland hardwood forest, Gadsden County, Florida, 19 June 1994–19 June 1995.

Date	Precip.	Max. temp.	Min. temp	Salamanders	Anurans	Turtles	Lizards	Snakes
June 1994	82	36	20	32.5	35.0	2.5	6.2	2.5
July 1994	195	33	21	29.0	23.0	0	4.0	0
	123	35	20	13.0	33.0	1.0	1.0	0
Aug 1994	240	34	19	15.0	39.0	0	1.0	0
	282	31	21	16.1	37.5	1.1	1.1	1.1
Sep 1994	18	33	18	7.5	17.5	0	1.2	2.5
	353	30	18	24.0	32.0	0	6.0	5.0
Oct 1994	341	29	14	32.5	45.0	0.8	0.8	2.5
	42	29	9	11.0	11.8	0.8	3.2	0.8
Nov 1994	16	30	7	15.0	2.3	0	1.2	0
	120	27	6	32.8	3.8	0	2.8	0
Dec 1994	66	24	3	25.0	0	0	0.8	0.8
	27	21	2	11.0	0	0	1.0	0
Jan 1995	72	24	0	32.1	1.1	0	1.1	0
	48	25	−1	1.1	0	0	1.1	0
Feb 1995	66	26	−5	6.9	2.3	0	1.2	0
	44	33	3	5.5	0.8	0	1.6	0
Mar 1995	45	34	2	12.2	0.9	0	2.8	0
	109	30	10	8.1	8.1	0	4.6	1.2
Apr 1995	40	28	5	9.6	13.9	0	3.2	0
	11	37	9	6.6	19.7	1.9	12.2	0
May 1995	160	35	11	19.7	43.1	0	4.7	0.9
	0	38	16	1.8	15.0	0.9	5.3	1.8
June 1995	243	38	15	20.6	22.5	0.9	4.7	1.9

during the latter two months and 81.6% of all reptile captures occurring from April to October. The spring peak corresponds with most breeding activity, and the fall peak is typically attributed to the presence of neonates. However, of the 23 reptile captures in September and October, only three were neonates and five were immature individuals. The three-fold increase in reptile captures from the first half to the last half of April coincided with an increase of 9°C in maximum air temperature (Table 1). Ground skinks (*Scincella lateralis*) comprised 67% of reptile captures during the latter half of April.

Linear regression indicated that bimonthly anuran capture rates were positively correlated with minimum ($F = 36.9$, 23 df, $p < 0.0001$) and maximum ($F = 11.1$, 23 df, $p = 0.003$) temperatures, but 61% of the observed variation in anuran capture rates was accounted for by minimum temperature compared to only 30% for maximum temperature. Anuran capture rates were also positively correlated with amount of precipitation ($F = 22.0$, 23 df, $p = 0.0001$), which accounted for 48% of the observed variation in anuran capture rates (minimum temperature and precipitation combined accounted for 71% of the observed variation). Anurans were seldom captured during the cooler months, when relatively little precipitation was recorded (Table 1). Of 412 anuran captures, 95.6% occurred from April to October. All but seven of 288 southern toads (*Bufo terrestris*), the most frequently captured species, were trapped during this period. Immature individuals made up a large percentage of anuran captures, including 50.7% of all southern toad captures and 58.6% of all ranid frog captures. No newly metamorphosed anurans were captured, indicating that no natal ponds were near the study area. Few winter-breeding anuran species, such as the southern spring peeper (*Pseudacris crucifer bartramiana*), were captured, except the Florida leopard frog (*Rana s. sphenocephala*), which predominantly breeds in winter.

Salamander captures were more evenly distributed throughout the year than anuran captures (Table 1). Although bimonthly salamander capture rates were positively correlated with amount of precipitation (F = 8.23, 23 df, p = 0.009), precipitation explained only 24% of the observed variation in salamander capture rates, which showed no correlation with minimum or maximum temperature. The fewest salamanders were captured from February to April. At least 50% of the individuals of the three most frequently captured salamander species were trapped during their breeding seasons, which were May to July for the southeastern slimy salamander, July to September for the three-lined salamander (*Eurycea guttolineata*), and November to mid-March for the southern two-lined salamander (*E. cirrigera*). The minimal overlap among breeding seasons of these three species helped account for the year-round activity pattern exhibited by salamanders.

Sampling efficiency—The three arrays captured 811 amphibians of 18 species and 103 reptiles of 14 species during the one-year study (Table 2), or 74.1 amphibians and 9.4 reptiles per 100 array-days. Calculations of capture rates include recaptured individuals. Of the 871 herpetofaunal captures whose recapture status could be confirmed, 116 (13.3%) were recaptures. The most frequently recaptured species were the ground skink (36.4%), southern toad (17.7%), and southeastern slimy salamander (17.1%). Recapture rates were 8.9% for three-lined salamanders and 13.9% for southern two-lined salamanders. Recapture rates would have been higher if 64 individuals had not died in the traps.

The mortality rate for trapped amphibians was 6.2%, primarily from desiccation, and for reptiles was 3.9%. Recapture status could not be confirmed for 43 animals because they either were dead and had lost toes or limbs or were not marked (i.e., small snakes and escapees). The calculated recapture rates were probably biased for salamanders because of toe regeneration.

One-half the total number of species trapped were captured during the first month of trapping (19 June–13 July 1994). Six additional species were trapped in September, and five new species were trapped in October. Within 98 days of initiation of trapping (by 25 September), 75% of the final species

TABLE 2. Herpetofaunal captures along drift fences in upland hardwood or mixed forest in Florida near Havana in Gadsden County, Lake Talquin WMA in Leon County, Woodyard Hammock in Leon County, Big Shoals WMA in Hamilton County, and Chassahowitzka WMA in Hernando County. Data are also included from a gas pipeline trench through hardwood forests in Gadsden County. An X indicates the taxon was observed but not trapped in the study area.

Taxa	Havana[a]	Talquin[b]	Woodyard[c]	Big Shoals[d]	Chassahowitzka[e]	Pipeline[f]
Salamanders						
Ambystoma opacum	1	0	264	0	0	2
A. talpoideum	0	0	22	0	0	0
Amphiuma pholeter	0	2	0	0	0	0
Desmognathus apalachicolae	3	104	0	0	0	0
Eurycea cirrigera	132	459	1	0	0	8
E. guttolineata	151	1,000	0	0	0	20
E. quadridigitata	0	0	0	51	0	0
Hemidactylium scutatum	7	1	0	0	0	2
Notophthalmus viridescens	14	33	1	2	0	10
Plethodon grobmani	86	13	18	24	0	1
Pseudotriton montanus	0	0	0	8	0	0
P. ruber	4	52	0	0	0	0
Unidentified	1	0	0	0	0	0
Anurans						
Acris crepitans	7	0	0	0	0	18
A. gryllus	0	11	8	3	0	0
Bufo terrestris	288	48	28	49	3	6
Eleutherodactylus planirostris	1	0	0	0	66	0
Gastrophryne carolinensis	23	26	20	4	115	28
Hyla avivoca	0	0	0	0	0	48
H. chrysoscelis	X	2	1	0	1	74
H. cinerea	15	5	2	0	1	26
H. femoralis	0	0	0	0	0	1
H. squirella	6	1	0	0	12	45

TABLE 2. Continued.

Taxa	Havana[a]	Talquin[b]	Woodyard[c]	Big Shoals[d]	Chassahowitzka[e]	Pipeline[f]
Pseudacris crucifer	1	11	2	10	0	5
Rana catesbeiana	11	0	2	0	5	23
R. clamitans	20	201	6	12	0	8
R. sphenocephala	38	181	9	9	86	1
Scaphiopus holbrookii	0	19	24	1	0	35
Unidentified	2	0	0	0	1	2
No. amphibians	811	2,169	408	173	290	363
No. amphibians/array-day × 100	74.1	167.4	16.8	13.7	48.3	N/A
No. amphibians/km-day	32.5	57.7	6.8	5.2	16.5	15.4
Turtles						
Chelydra serpentina	X	10	0	1	0	0
Kinosternon baurii	0	0	0	X	3	0
K. subrubrum	3	22	0	1	2	2
Terrapene carolina	5	X	0	0	0	0
Trachemys scripta	1	0	0	0	0	0
Lizards						
Anolis carolinensis	21	29	12	17	9	5
Cnemidophorus sexlineatus	0	0	4	0	0	0
Eumeces fasciatus	2	4	0	1	0	0
E. inexpectatus	0	0	0	0	21	0
E. laticeps	13	9	2	8	21	0
Sceloporus undulatus	0	0	0	1	0	0
Scincella lateralis	38	6	1	39	114	0
Unidentified	0	0	0	0	1	0

TABLE 2. Continued.

Taxa	Havana[a]	Talquin[b]	Woodyard[c]	Big Shoals[d]	Chassahowitzka[e]	Pipeline[f]
Snakes						
Agkistrodon piscivorus	1	1	0	0	0	0
Cemophora coccinea	1	0	0	0	0	0
Coluber constrictor	2	11	2	8	11	1
Diadophis punctatus	9	13	0	1	3	1
Elaphe guttata	X	0	0	0	1	0
E. obsoleta	1	1	1	2	3	X
Farancia abacura	0	2	0	0	1	0
Lampropeltis triangulum	0	0	0	1	0	0
Micrurus fulvius	0	0	0	X	8	0
Nerodia fasciata	X	1	0	0	0	0
Sistrurus miliarius	0	0	0	1	0	0
Storeria occipitomaculata	3	5	0	3	12	0
Thamnophis sauritus	0	0	0	0	11	0
T. sirtalis	3	0	0	1	0	0
Virginia valeriae	X	0	0	0	0	2
Unidentified	0	0	0	0	1	0
No. reptiles	103	114	22	85	222	11
No. reptiles/array-day × 100	9.4	8.8	0.9	6.7	37.0	n/a
No. reptiles/km-day	4.1	3.0	0.2	2.5	12.6	0.5

[a] This study; [b] Enge, unpubl. data; [c] Means and Campbell, 1981; [d] Enge and P. Southall, unpubl. data; [e] Enge and K. Wood, unpubl. data; [f] Enge et al., 1996.

total had been captured. All but one species were detected within the first 211 days of trapping (by 16 January). The final new species, the southern black racer (*Coluber constrictor priapus*), was captured 343 days into the study.

The use of multiple arrays was important in compiling a comprehensive species list. Eight species were captured in only one array, and no array captured >85% of the total species. Array 2 captured only 59% of the total species (no unique ones), despite catching the largest number of individuals. Array 1 captured the fewest number of individuals, but it captured the most species (27), including five unique ones.

Eight species not captured in drift fence traps were observed on the site, although some may have been restricted to ruderal habitats. In the forest, Cope's gray treefrogs (*Hyla chrysoscelis*) were occasionally heard calling. Along the Salem Branch tributary, an eastern earth snake (*Virginia v. valeriae*) and two banded water snakes (*Nerodia f. fasciata*) were observed, and a partially depredated nest of the Florida snapping turtle (*Chelydra serpentina osceola*) was found. One rough green snake (*Opheodrys aestivus*), two corn snakes (*Elaphe guttata*), and one eastern glass lizard (*Ophisaurus ventralis*) were observed in the old field adjacent to the forest, and several six-lined racerunners (*Cnemidophorus s. sexlineatus*) were observed in the lawn area. Corn, rough green, and eastern earth snakes might have been captured in the forest if trapping had been extended. No additional species were detected by coverboards, under which the southern toad, Gulf Coast box turtle (*Terrapene carolina major*), green anole (*Anolis carolinensis*), ground skink, broadhead skink (*Eumeces laticeps*), southern ringneck snake (*Diadophis p. punctatus*), Florida redbelly snake (*Storeria occipitomaculata obscura*), southern black racer, corn snake, and gray rat snake (*Elaphe obsoleta spiloides*) were detected.

Drift fences are often effective at catching cryptic or nocturnal species that are infrequently observed, and 14 species on the site were detected only by the use of drift fences. However, drift fences under-sampled arboreal species, and the size of the funnel openings (6 cm maximum) of the traps precluded the capture of large turtles. I observed >20 box turtles in the woods, often near drift fences, but only five were captured in funnel traps. Trapped box turtles were either immature or small adults (≤105 mm carapace length); the latter had forced their way through the funnel openings. Circumstantial evidence indicated that turtles sometimes escaped from funnel traps by forcing their way out through the stapled bottom seam where the funnel fits in the trap cylinder. The green anole was not captured proportional to its abundance; unmarked individuals were frequently observed clinging to the fence or sheltering under shade covers.

DISCUSSION—*Sampling efficiency*—Drift fencing is most efficient at capturing small, surface-active herpetofauna and tends to under-sample large turtles, large snakes, and arboreal and fossorial species (Campbell and Christman, 1982; Dodd, 1991a; Greenberg et al., 1994). I trapped relatively few arboreal species and large snakes, and no large turtles. Treefrogs are an important component of many hardwood-dominated habitats, but hylid frogs (i.e., *Hyla* spp., *Pseudacris* sp., *Acris* sp.) accounted for only 3.2% of the herpetofaunal captures. Cope's gray treefrogs and southern spring peepers were heard calling but only one spring peeper was trapped. The potential abundance of hylid frogs is illustrated by herpetofaunal captures recorded from a gas pipeline trench that traversed hardwood forest habitat in Gadsden County, where seven species of hylid frogs accounted for 56.7% of all captures (Enge et al., 1996; Table 2).

Long-term studies using several survey techniques are necessary for comprehensive herpetofaunal inventories, and the duration of trapping required to compile a relatively complete species list for an area is dependent upon the number of arrays, the year(s) surveyed, and weather conditions. A small area can exhibit a succession of herpetofaunal communities over time and during different weather conditions. For example, over a five-year period, daily inspections of a 0.13-ha tract of land at the edge of an upland mixed forest in Alachua County, Florida, documented 18 amphibian and 20 reptile species, but ten of these species were not seen during the first two years of the study (Goin and Goin, 1953). During a one-year survey, some amphibian species dependent on ephemeral breeding ponds may not be detected because of unsuccessful reproduction for ≥1 year during drought periods (Pechmann et al., 1989; Dodd, 1992). Although additional sampling undoubtedly would have detected additional species, 75% of the species had been captured within 98 days of trapping initiation. If trapping had begun during a less productive time of year, such as winter, it would have taken longer to detect this percentage of species. In northern Florida, April to June and September to October are generally peak periods of herpetofaunal activity because of breeding and dispersal of young of the year. Because mostly amphibians were captured, periods of high precipitation accounted for most herpetofaunal captures, although reptiles exhibited bimodal activity.

Noteworthy findings—The capture of six individuals (one individual was recaptured) of the four-toed salamander (*Hemidactylium scutatum*) was noteworthy because only 15 specimens had been reported from eight localities in three counties in Florida (Means, 1992; Moler, 1995; Enge et al., 1996; Means, 1997). In addition to these records, however, previously unreported specimens have been captured during drift fence surveys in longleaf pine (*Pinus palustris*) flatwoods adjacent to an intermittent stream (Enge, Unpubl. data) and in xeric hammock (Francis and Etters, 1997) on Joe Budd Wildlife Management Area (WMA), Gadsden County, and in a floodplain along a steephead ravine on the south side of Lake Talquin on Talquin WMA, Leon County (Enge, Unpubl. data; Table 2).

Five of the reported four-toed salamander localities are in the Ochlockonee River drainage (Stevenson, 1958; Fugler and Folkerts, 1967; Moler, 1995; Enge et al., 1996; Means, 1997), the same drainage as my study area and the unreported localities. One reported locality was near the Ochlockonee River ≈8 km southeast of my study area (Stevenson, 1958), and another locality was along Hurricane Creek 6.7 km southwest of my study area (Moler, 1995).

The capture of four-toed salamanders in a variety of habitats indicates that this species, listed as rare by the Florida Committee on Rare and Endangered Plants and Animals (FCREPA), is probably more common than suspected and is not restricted to bottomland hardwood forests near sphagnous, boggy areas as previously thought (see Means, 1992). Sphagnum moss (*Sphagnum* spp.) has been indicated as a preferred nesting substrate (Means, 1992), but sphagnum moss was absent on this study site, the xeric hammock, and the slope forest traversed by the pipeline trench (Enge et al., 1996).

Two female four-toed salamanders were captured in early December at Array 1, which was situated in a shallow, seepage area with clumps of unidentified moss that may have been used for nesting. Means (1992) speculated that egg laying probably occurs in March or April in Florida, but I suspect that eggs are laid in winter in Florida. The other four salamanders were captured in a terrestrial situation at Array 2, which was in the vicinity of fallen logs and adjacent to a small seepage stream, in January, April, and May (two individuals).

Three Apalachicola dusky salamanders (*Desmognathus apalachicolae*) were captured in the seep at Array 1. This species typically inhabits ravines in the Apalachicola River drainage but is also found in ravines along the Ochlockonee River and its two major tributaries, Little River and Telogia Creek (Means and Karlin, 1989).

Herpetofaunal community composition—The upland hardwood forest habitat type is often considered to be the oldest and most persistent terrestrial habitat in Florida (Webb, 1990), although there is some evidence that the longleaf pine community may be just as old (Means, 1996). In the past, a northern corridor transmitted mesic taxa southward through Florida's central axis, especially during periods of high sea levels when summers were relatively cool (Neill, 1957). The relatively high percentage of broad-leaved evergreen tree and shrub species in upland hardwood forests provide year-round cover for arboreal species, forage for phytophagous arthropods eaten by insectivorous herpetofauna (Harris and Vickers, 1984), and amelioration of extremes in temperature and relative humidity during the winter (Wolfe et al., 1988). Canopy closure creates a cooler, more humid microclimate, facilitating the survival of species typical of higher latitudes. The abundant hardwood leaf litter and the presence of seeps and streams associated with the rolling topography provide suitable environmental conditions for many salamander species, which are a more prominent component of mesic uplands than of other terrestrial communities. The herpetofaunal community of the forest studied consisted predominantly of amphibians, especially the southern toad, three-lined salamander, southern two-lined salamander, and southeastern slimy salamander. Three species of ranid frogs and four species of hylid frogs were captured (Table 2).

The study area had a diverse and abundant salamander community because of the presence of spring seeps and streams. The seeps were apparently unpolluted, but the water quality in the tributary of Salem Branch was probably degraded because it flowed from an impoundment used to provide water for a commercial nursery; the stream was frequently littered with plastic flower pots, black plastic sheeting, and root balls.

The quantity and permanence of water in seeps and streams in upland hardwood forests are important, especially for amphibians with long aquatic larval stages. The three-lined salamander normally has a larval period of four to five months and can successfully breed in ephemeral ponds, whereas the smaller two- lined salamander has a larval period of 12–16 months and requires a perennial source of water (Bruce, 1982). The Apalachicola dusky salamander has a larval period of less than one year, and the larvae frequent shallower water (25–75 mm deep) than those of the southern two-lined salamander (Means and Karlin, 1989). Larvae of the southern red salamander (*Pseudotriton ruber vioscai*) live 2–3 years (Bruce, 1972) in small pockets of fluid muck along stream and seepage margins (Means and Karlin, 1989).

No reptile species are specific to upland hardwood forest, although several species are year-round residents or use it seasonally for cover or foraging. Heliophilic terrestrial reptiles are relatively rare because of limited sunlight penetration to the forest floor. Skinks are the predominant reptile component because they prefer moister, cooler conditions than most other lizards. Arboreal insectivores (e.g., treefrogs, green anoles, and rough green snakes) feeding on phytophagous invertebrates occur in the canopy, whereas terrestrial insectivores (e.g., southern toads, ranid frogs, and salamanders) feeding on detritivores predominate on the forest floor (Wolfe et al., 1988). Upland hardwood forests apparently do not have a diverse snake community, but arboreal or semiarboreal species (e.g., corn and rough green snakes) that are infrequently captured by drift fences were probably present in addition to the seven species trapped. The southern ringneck snake was trapped most frequently and was also observed under shade covers.

Because of clearing and habitat fragmentation of surrounding upland areas and persecution by human residents, the study area probably lacked certain upland species that occasionally forage in riparian areas, such as the eastern diamondback rattlesnake (*Crotalus adamanteus*) and eastern hognose snake (*Heterodon platirhinos*). Snake species that might be detected in the study area during longer or more intensive survey efforts include the eastern kingsnake (*Lampropeltis g. getula*), scarlet kingsnake (*L. triangulum elapsoides*), and eastern coral snake (*Micrurus fulvius*).

Comparisons with other studies—Woodyard Hammock, a virgin upland hardwood forest at Tall Timbers Research Station north of Tallahassee, Leon

County, was surveyed for >4 years using drift fences (Means and Campbell, 1981). Despite Woodyard Hammock and my study area both containing upland hardwood forest in the Tallahassee Hills physiographic region (Puri and Vernon, 1964), I captured a different assemblage of species, especially of salamanders (Table 2). The predominant species trapped in Woodyard Hammock was the marbled salamander (*Ambystoma opacum*), which breeds in woodland depressions. Common upland species, such as the mole salamander (*Ambystoma talpoideum*), eastern spadefoot (*Scaphiopus holbrookii*), and six-lined racerunner, were captured in Woodyard Hammock but not in this study's forest. The scarcity or absence of the aforementioned amphibian species in my study area was probably attributable to the lack of nearby ephemeral wetlands, which are needed by many breeding amphibian species (Moler and Franz, 1987; LaClaire and Franz, 1990). Most upland areas in the vicinity consisted of ruderal habitats no longer containing temporary wetlands. Degradation of uplands and ephemeral wetlands by residential development may extirpate local populations of anurans (Delis et al., 1996). Most upland wetlands in the vicinity were permanent, manmade ponds (often used for irrigation by nurseries and stocked with fish) that provided suitable breeding sites for bullfrogs (*Rana catesbeiana*), Florida leopard frogs, and green treefrogs (*Hyla cinerea*). The Salem Branch tributary was impounded at its headwaters ≈1 km upstream from the study area.

Despite Woodyard Hammock being located on the broad bottomland of a small stream course, few stream-dwelling salamander species were captured. Forested areas in the vicinity of my study area were primarily restricted to the gully-eroded ravines along streams, but seepage areas along the slopes and small streams provided suitable breeding habitat for southern two-lined, three-lined, Apalachicola dusky, four-toed, and southern red salamanders. Of these species, only one southern two-lined salamander was captured in Woodyard Hammock (Table 2), which lacked seepage areas along the ephemeral stream (Means, 1997).

The herpetofaunal community of my study area closely resembled that of upland hardwood forest along seepage streams in a steephead ravine south of Lake Talquin in Leon County, which was surveyed using identical array and trap configurations (Enge, Unpubl. data; Table 2). The species composition of these two sites was similar except for the presence of the northern cricket frog (*Acris c. crepitans*) in my study area and the presence of the Florida cricket frog (*A. gryllus dorsalis*), one-toed amphiuma (*Amphiuma pholeter*), and eastern mud snake (*Farancia a. abacura*) in the steephead ravine. A drift fence survey using funnel and pitfall traps in slope forest habitat on Big Shoals WMA, Hamilton County (Enge and P. Southall, Unpubl. data; Table 2), sampled habitats similar to my study area except for the presence of intact uplands, including sandhills. A small stream and mucky pools (hog wallows) along the base of the slope at Big Shoals provided suitable habitat for rusty mud (*Pseudotriton montanus floridanus*) and dwarf (*Eurycea quadridigitata*) salamanders, which replaced the southern red, southern two-lined, and three-lined salamanders found in similar habitats in Florida's panhandle.

In upland mixed forest farther south in peninsular Florida on Chassahowitzka WMA, Hernando County, much of the reptile community was similar to hardwood forests in northern Florida, except for the presence of southeastern five-lined skinks (*Eumeces inexpectatus*) and bluestripe ribbon snakes (*Thamnophis sauritus nitae*) instead of five-lined skinks and eastern garter snakes (*T. s. sirtalis*) (Enge and K. Wood, Unpubl. data; Table 2). The Chassahowitzka site contained many of the same anuran species as more northerly sites, with the primary differences being the absence of bronze frogs and the abundance of nonnative greenhouse frogs (*Eleutherodactylus planirostris*). The most obvious difference between the herpetofaunal community at Chassahowitzka and that at any other site was the absence of salamanders, despite using drift fencing techniques identical to those in this study and in the Leon County steephead ravine. Maximal herpetofaunal species density (107 species) occurs in Gadsden and nearby panhandle counties, and it declines as one progresses southward through the peninsula (Kiester 1971, Means and Simberloff 1987, Auth, 1989). Salamander species density exhibits the most precipitous southward decline; 19 of Florida's 26 salamander species are restricted to the northern peninsula and/or panhandle (Enge, 1997a). If wetter areas had been sampled in Chassahowitzka's upland mixed forest, one-toed amphiumas, dwarf salamanders, and peninsula newts (*Notophthalmus viridescens piaropicola*) might have been trapped, because these species occurred in adjacent hydric hammock habitat (Enge and K. Wood, Unpubl. data).

Amphibian capture rates were lower in this study than in the Leon County steephead ravine, which sampled wetter microhabitats, but over twice as high as in other studies in similar habitats (Table 2). Two *Eurycea* species accounted for 35% of all amphibian captures in this study and 67% in the steephead ravine. Woodyard Hammock and Big Shoals, both of which were surveyed using both pitfall and funnel traps, had similar amphibian capture rates, but Big Shoals had a more depauperate amphibian fauna (Table 2). Chassahowitzka had low amphibian species richness and an intermediate amphibian capture rate (per km of fence/trench) similar to that from the pipeline trench in Gadsden County (Table 2), which functioned as a linear pitfall trap. The pipeline trench was effective at capturing hylid frogs, which are under-sampled by drift fences (Enge et al., 1996).

Reptile capture rates and species richness were similar between this study and the Leon County steephead ravine, and species richness was approximately twice that of Woodyard Hammock and Big Shoals (Table 2). The reptile capture rate in Woodyard Hammock was much lower than in other drift fence studies, which might have been due to limited insolation and differences in techniques, specifically in the size and condition of the funnel and pitfall traps (#10 cans) used. No turtles or five-lined skinks were trapped in Woodyard Hammock, and only two snake species were trapped compared to seven species in this study. The Chassahowitzka site had a reptile capture rate over three times that of any other site, primarily due to an abundance of ground skinks, which accounted for 51% of all reptile captures (Table 2).

Conclusions and recommendations—In Florida, upland longleaf pine and scrub communities contain many of the state's most characteristic and threatened species (Noss, 1988), but many amphibian species are dependent upon panhandle streams and their associated forests (Wolfe et al. 1988; Enge, 1997a). Leaving strips of hardwood forest as buffer zones around seepage wetlands and along stream courses during silvicultural operations minimizes erosion from surrounding cleared upland areas and promotes a diverse amphibian community in rural or residential areas. Species with restricted distributions in Florida, such as the four-toed salamander and Apalachicola dusky salamander, can survive along streams and associated seeps in hardwood forests in a fragmented landscape. The future survival of a diverse amphibian community appears secure in the Ochlockonee drainage as long as mature hardwoods remain along the streams and the quantity and quality of water remain high in these systems; however, some upland amphibian species dependent upon ephemeral wetlands for breeding may be in trouble. Because of the dependence of many amphibian species on clean water for successful reproduction, it is important to minimize stream siltation from erosion and watering of livestock, and pollution (e.g., manure, fertilizer, and pesticide runoff). Seepage areas resulting from perched water tables provide suitable adult and larval microhabitats for certain amphibian species and need to be protected from excessive tapping of ground water for agriculture or residential use.

If timber harvesting is conducted in upland hardwood and slope forests, selective logging and minimal surface disturbance of upland hardwood and slope forests would be the least detrimental to amphibians (Dodd, 1991b) because most are dependent upon a heavy canopy cover ameliorating temperature and humidity extremes. Clearcutting of hardwoods on slopes would decrease shading, reduce leaf litter, increase soil-surface temperatures, and reduce soil-surface moisture (Bury, 1983; Ash, 1988; Raphael, 1988; Welsh, 1990); such conditions would be unfavorable for many amphibian species, especially if erosion resulted in sedimentation of streams and warmer water temperatures (Corn and Bury, 1989). Timber harvesting of hardwood forests in the southern Appalachians adversely affected many salamander populations (Ash, 1988; Petranka et al., 1993), but plethodontid species gradually recolonized clearcuts over a period of four to 15 years as the moist leaf-litter layer developed (Ash, 1997).

Florida is losing 1% of its forest area each year, and a statewide greenways system has been recommended to minimize the deleterious effects of habitat fragmentation and to conserve biodiversity (Florida Greenways Commission, 1994). Riparian greenways in developed areas and stream management zones in harvested areas can provide suitable hardwood habitat and possible movement corridors for wildlife species (Rudolph and Dickson, 1990; Noss, 1993; Dupuis et al., 1995), which are accustomed to linear habitats in Florida because hardwood forests are typically confined by periodic fires to narrow bands along streams and along slopes between upland sand/clayhill pinelands and bottomland lake margin or floodplain forests (Platt and Schwartz, 1990).

Studies should be conducted along streams of different sizes and types in northern Florida to determine the width of streamside buffer zones necessary to conserve wildlife populations and preserve water quality. A riparian greenway's width should be proportional to the size of the runoff area, the steepness of the slope, and the intensity and type of disturbances in adjacent upland areas (Binford and Buchenau, 1993). The necessary corridor width will also depend upon its habitat structure and quality, human use patterns, and the particular species expected to use the corridor (Noss, 1987). In my study area, the buffer zone of upland hardwood forest, which extended for 75–200 m from the second-order stream to ruderal habitats at the top of the slope, provided habitat for at least 37 herpetofaunal species, 12 of which were aquatic (mostly turtles) or dependent upon the stream and/or seeps for larval habitat (mostly salamanders). Retention during logging of a riparian buffer zone at least 15–30 m wide on each side of streams is often recommended in the Pacific Northwest (Newbold et al., 1980; Budd et al., 1987) and eastern United States (Corbett et al., 1978), but these widths may be inadequate to conserve some wildlife species and prevent erosion (Noss, 1993; Binford and Buchenau, 1993, Spackman and Hughes, 1995). A 168-m buffer zone was recommended on each side of rivers in east central Florida to protect wetland wildlife habitat (Brown et al., 1990).

If forested riparian zones are too narrow, there may be a reduction in stream water quality and production of woody debris and leaves, which can provide >99% of the energy in the stream food web, especially along headwater streams (Likens et al., 1970). Narrow corridors and small forest fragments are also more influenced by the penetration of edge effects, including increased mortality from opportunistic meso-predators (Noss, 1993) and microclimatic changes, such as increased light and temperature and decreased humidity and litter moisture (Matlack, 1993). In young pine plantations in eastern Texas, amphibians (anurans except for one salamander) and reptiles were more abundant in wider (30–95 m) than narrower (0–25 m) streamside zones, apparently because of the presence of a closed canopy and abundant leaf litter (Rudolph and Dickson, 1990).

Additional herpetofaunal surveys using drift fences and other methods in developed areas could provide important information on the ability of species to survive in fragmented and disturbed habitats. Most drift fence surveys target relatively pristine habitats or examine the effects of forestry practices, but more information is needed on the herpetofauna of ruderal habitats and different-sized corridors or "islands" of undisturbed habitat.

ACKNOWLEDGMENTS—I would like to thank G. L. Sprandel for assistance installing drift fences, K. N. Wood for assistance collecting data, and D. T. Cobb, D. G. Cook, D. B. Means, W. E. Meshaka, Jr., P. E. Moler, and D. A. Wood for comments on earlier drafts of the manuscript. Materials for fences and traps were purchased using monies from the Florida Game and Fresh Water Fish Commission.

LITERATURE CITED

ASH, A. 1988. Disappearance of salamanders from clearcut plots. J. Elisha Mitchell Scient. Soc. 104:116–122.

———. 1997. Disappearance and return of plethodontid salamanders to clearcut plots in the southern Blue Ridge Mountains. Conserv. Biol. 11:983–989.

AUTH, D. L. 1989. Amphibian and reptilian density in Florida counties. Gainesville Herp. Soc. Newsl. 5(8):7–14.

BINFORD, M. W. AND M. J. BUCHENAU. 1993. Riparian greenways and water resources. Pp. 69–104. *In*: SMITH, D. S. AND P. C. HELLMUND (eds.). Ecology of Greenways. Univ. Minnesota Press, Minneapolis, MN.

BROWN, M. T., J. M. SCHAEFER, AND K. H. BRANDT. 1990. Buffer zones for water, wetlands and wildlife in east central Florida. Cent. for Wetlands Publ. No. 89-07, Univ. Florida, Gainesville, FL. 71 pp.

BRUCE, R. C. 1972. The larval life of the red salamander, *Pseudotriton ruber*. J. Herp. 6:43–51.

———. 1982. Larval periods and metamorphosis in two species of salamanders of the genus *Eurycea*. Copeia 1982:117–127.

BUDD, W. W., P. L. COHEN, AND P. R. SAUNDERS. 1987. Stream corridor management in the Pacific Northwest: I. Determination of stream-corridor widths. Environ. Manage. 11:587–597.

BURY, R. B. 1983. Differences in amphibian populations in logged and old-growth redwood forest. Northwest Sci. 57:167–178.

CAMPBELL, H. W. AND S. P. CHRISTMAN. 1982. Field techniques for herpetofaunal community analysis. Pp. 193–200. *In*: SCOTT, N. J., JR. (ed.). Herpetological Communities. U.S. Fish Wildl. Serv, Wildl. Res. Rept. No. 13.

CORBETT, E. S., J. A. LYNCH, AND D W. E. SOPPER. 1978. Timber harvesting practices and water quality in the eastern United States. J. For. 76:484–488.

CORN, P. S. 1994. Straight-line drift fences and pitfall traps. Pp. 109–117. *In*: HEYER, W. R., M. A. DONNELLY, R. W. MCDIARMID, L. C. HAYEK, AND M. S. FOSTER (eds.). Measuring and Monitoring Biological Diversity: Standard Methods Amphibians. Smithsonian Inst. Press, Washington, D.C.

——— AND R. B. BURY. 1989. Logging in western Oregon: responses of headwater habitats and stream amphibians. For. Ecol. Manage. 29:39–57.

DELIS, P. R., H. R. MUSHINSKY, AND E. D. MCCOY. 1996. Decline of some west-central Florida anuran populations in response to habitat degradation. Biodivers. Conserv. 5:1579–1595.

DODD, C. K., JR. 1991a. Drift fence-associated sampling bias of amphibians at a Florida sandhills temporary pond. J. Herp. 25:296–301.

———. 1991b. The status of the Red Hills salamander *Phaeognathus hubrichti,* Alabama, USA, 1976–1988. Biol. Conserv. 55:57-75.

———. 1992. Biological diversity of a temporary pond herpetofauna in north Florida sandhills. Biodivers. Conserv. 1:125–142.

DUPUIS, L. A., J. N. M. SMITH, AND F. BUNNELL. 1995. Relation of terrestrial-breeding amphibian abundance to tree-stand age. Conserv. Biol. 9:645–653.

ENGE, K. M. 1997a. Habitat occurrence of Florida's native amphibians and reptiles. Florida Game and Fresh Water Fish Comm. Tech. Rept. No. 16, Tallahassee, FL. 44 pp.

———. 1997b. A standardized protocol for drift-fence surveys. Florida Game and Fresh Water Fish Comm. Tech. Rept. No. 14, Tallahassee, FL. 68 pp.

———. 1997c. Use of silt fences and funnel traps for drift fences. Herp. Rev. 28:30–31.

———, D. T. COBB, G. L. SPRANDEL, AND D. L. FRANCIS. 1996. Wildlife captures in a pipeline trench in Gadsden County, Florida. Florida Scient. 59:1–11.

FLORIDA GREENWAYS COMMISSION. 1994. Creating a statewide greenways system for people. . .for wildlife. . .for Florida. Report to the Governor. Florida Dept. Environ. Prot., Off. Greenways and Trails, Tallahassee, FL. 186 pp.

FLORIDA NATURAL AREAS INVENTORY. 1990. Guide to the natural communities of Florida. Florida Nat. Areas Inventory and Florida Dept. Nat. Resour., Tallahassee, FL.

FRANCIS, D. L. AND R. W. ETTERS. 1997. Florida Game and Fresh Water Fish Comm., Route 7, Box 3055, Quincy, FL 32351. Pers. commun.

FUGLER, C. M. AND G. W. FOLKERTS. 1967. A second record of *Hemidactylium* from Florida. Herpetologica 23:60.

GREENBERG, C. H., D. G. NEARY, AND L. D. HARRIS. 1994. A comparison of herpetofaunal sampling effectiveness of pitfall, single-ended, and double-ended funnel traps used with drift fences. J. Herp. 28:319–324.

GOIN, C. J. AND O. B. GOIN. 1953. Temporal variation in a small community of amphibians and reptiles. Ecology 34:406–408.

HARRIS, L. D. AND C. R. VICKERS. 1984. Some faunal community characteristics of cypress ponds and the changes induced by perturbations. Pp. 171–185. *In:* EWEL, K. C. AND H. T. ODUM (eds.). Cypress Swamps. Univ. Presses Florida, Gainesville, FL.

JONES, K. B. 1986. Amphibians and reptiles. Pp. 267–290. *In*: COOPERRIDER, A. Y., R. J. BOYD, AND H. R. STUART (eds.). Inventory and Monitoring of Wildlife Habitat. USDI Bur. Land Manage. Serv. Cent., Denver, CO.

KAUTZ, R. S. 1993. Trends in Florida wildlife habitat 1936–1987. Florida Scient. 56:7–24.

KIESTER, A. R. 1971. Species density of North American amphibians and reptiles. Syst. Zool. 20:127–137.

LACLAIRE, L. V. AND R. FRANZ. 1990. Importance of isolated wetlands in upland landscapes. Pp. 9–15. *In*: KELLY, M. (ed.). Proc. Second Ann. Mtg. Florida Lake Manage. Soc., Winter Haven, FL.

LIKENS, G. E., F. H. BORMANN, N. M. JOHNSON, D. W. FISHER, AND R. S. PIERCE. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecol. Monogr. 40:23–47.

MATLACK, G. R. 1993. Microenvironment variation within and among forest edge sites in the eastern United States. Biol. Conserv. 66:185–194.

MEANS, D. B. 1992. Four-toed salamander, *Hemidactylium scutatum* (Schlegel). Pp. 54–57. *In*: MOLER, P. E. (ed.). Rare and Endangered Biota of Florida. Volume III. Amphibians and Reptiles. Univ. Press Florida, Gainesville, FL.

———. 1996. Chapter 15. Longleaf pine forest, going, going. . .. Pp. 210–229. *In*: DAVIS, M. B. (ed.). Eastern Old-growth Forest: Prospects for Rediscovery and Recovery. Island Press, Washington, D.C.

———. 1997. Coastal Plains Inst., 1313 N. Duval Street, Tallahassee, FL 32303. Pers. commun.

——— AND H. W. CAMPBELL. 1981. Effects of prescribed burning on amphibians and reptiles. Pp. 89–96. *In*: WOOD, G. W. (ed.). Prescribed Fire and Wildlife in Southern Forests. Belle W. Baruch For. Sci. Inst., Clemson Univ., Georgetown, SC.

——— AND A. A. KARLIN. 1989. A new species of *Desmognathus* from the eastern Gulf Coastal Plain. Herpetologica 45:37–46.

——— AND D. SIMBERLOFF. 1987. The peninsula effect: habitat-correlated species declines in Florida's herpetofauna. J. Biogeogr. 14:551–568.

MOLER, P. E. 1995. Florida Game and Fresh Water Fish Comm., 4005 South Main St., Gainesville, FL 32601. Pers. commun.

——— AND R. FRANZ. 1987. Wildlife values of small, isolated wetlands in the southeastern coastal plain. Pp. 234–241. *In*: ODOM, R. R., K. A. RIDDLEBERGER, AND J. C. OZIER (eds.). Proc. Third S.E. Nongame and Endangered Wildl. Symp., Georgia Dept. Nat. Resour., Game and Fish Div.

NEWBOLD, J. D., D. C. ERMANN, AND K. B. ROBY. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37:1076–1085.

NEILL, W. T. 1957. Historical biogeography of present-day Florida. Bull. Florida State Mus., Biol. Sci. 2:175–220.

NOSS, R. F. 1987. Corridors in real landscapes: a reply to Simberloff and Cox. Conserv. Biol. 1:159–164.

———. 1988. The longleaf pine landscape of the Southeast: Almost gone and almost forgotten. Univ. Michigan School Nat. Resour., Endangered Species Update 5(5):1–8.

———. 1993. Wildlife corridors. Pp. 43–68. *In*: SMITH, D. S. AND P. C. HELLMUND (eds.). Ecology of Greenways. Univ. Minnesota Press, Minneapolis, MN.

PECHMANN, J. H. K., D. E. SCOTT, J. W. GIBBONS, AND R. D. SEMLITSCH. 1989. Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. Wetlands Ecol. Manage. 1:3–11.

PETRANKA, J. W., M. E. ELDRIDGE, AND K. E. HALEY. 1993. Effects of timber harvesting on southern Appalachian salamanders. Conserv. Biol. 7:363–370.

PLATT, W. J. AND M. W. SCHWARTZ. 1990. Temperate hardwood forests. Pp. 194–229. *In*: MYERS, R. L. AND J. J. EWEL (EDS.). Ecosystems of Florida. Univ. Cent. Florida Press, Orlando, FL.

PURI, H. S. AND R. O. VERNON. 1964. Summary of the geology of Florida and a guidebook to the classic exposures. Florida Geol. Surv. Spec. Publ. No. 5 (revised). 312 pp.

RAPHAEL, M. G. 1988. Long-term trends in abundance of amphibians, reptiles, and mammals in douglas-fir forests of northwestern California. Pp. 11–22. *In*: SZARO, R. C., K. E. SEVERSON, AND D. R. PATTON (eds.). Management of Amphibians, Reptiles, and Mammals in North America. U.S. Dept. Agric. For. Serv. Gen. Tech. Rep. RM-166.

RUDOLPH, D. C. AND J. G. DICKSON. 1990. Streamside zone width and amphibian and reptile abundance. Southwest. Nat. 35:472–476.

SPACKMAN, S. C. AND J. W. HUGHES. 1995. Assessment of minimum stream corridor width for biological conservation: species richness and distribution along mid-order streams in Vermont, USA. Biol. Conserv. 71:325–332.

STEVENSON, H. M. 1958. A record of *Hemidactylium scutatum* in Florida. Copeia 1958:49.

STRAHLER, A. N. 1964. Section 4-II. Geology. Part II. Quantitative geomorphology of drainage basins and channel networks. Pp. 39–76. *In*: TE CHOW, V. (ed.). Handbook of Applied Hydrology. McGraw-Hill Book Co., New York, NY.

WEBB, S. D. 1990. Historical biogeography. Pp. 70–100. *In*: MYERS, R. L. AND J. J. EWEL (eds.). Ecosystems of Florida. Univ. Cent. Florida Press, Orlando, FL.

WELSH, H. H., JR. 1990. Relictual amphibians and old-growth forests. Conserv. Biol. 4:309–319.

WOLFE, S. H., J. A. REIDENAUER, AND D. B. MEANS. 1988. An ecological characterization of the Florida panhandle. U.S. Fish and Wildl. Serv. Biol. Rept. 88(12). 277 pp.

Florida Scient. 61(3/4): 141–159. 1998
Accepted: January 7, 1998

STATUS AND CONSERVATION OF SOUTHEASTERN MYOTIS MATERNITY COLONIES IN FLORIDA CAVES

JEFFERY A. GORE(1) AND JULIE A. HOVIS(2)

(1)Florida Game and Fresh Water Fish Commission, 3911 Highway 2321,
Panama City, FL 32409
(2)Florida Game and Fresh Water Fish Commission, 1239 S.W. 10th Street,
Ocala, FL 34474

ABSTRACT: *In Florida, female southeastern myotis (*Myotis austroriparius*) typically bear and rear their young in large maternity colonies in select caves. Because these maternity caves are rare and southeastern myotis females congregate in them each spring and summer, protection of the caves is important to the conservation of this species. Southeastern myotis maternity colonies have been reported from at least 19 Florida caves, but in 1991 and 1992 we found maternity colonies in 9 caves containing approximately 319,000 adults. Previous surveys found maternity roosts almost exclusively over water, but bats roosted over water in only 3 caves during our survey. Most caves showed evidence of past flooding, but risk of flooding was not significantly correlated with presence of maternity colonies. Of the 10 maternity caves we found unoccupied, all but 1 had entrances closed by landowners, the surrounding forest cleared, or showed evidence of vandalism. Failure of a roost to produce volant young was significantly associated with vandalism in caves. We suspect maternity colonies moved to new roosts following disturbance in their preferred caves, but lack of regular surveys and the potential movement of bats among caves precluded accurate assessments of trends in the number of occupied maternity caves or size of the maternity colonies. Our data suggest that the number of Florida caves that are both undisturbed by humans and suitable as maternity roosts for southeastern myotis is decreasing. We recommend that current and former maternity caves be protected from vandalism and that access into the caves be restricted during the maternity season.*

THE southeastern myotis (*Myotis austroriparius*) occurs throughout the Gulf coastal plain of the southeastern United States but is most abundant in Florida (Barbour and Davis, 1969; Jones and Manning, 1989). Here, unlike across most of their range, these bats commonly roost in large colonies in caves, especially in spring when females congregate in several select caves to bear and rear their young (Rice, 1957). To serve as bat maternity roosts, caves must be located close to suitable foraging areas and have rooms that provide the warm, stable temperatures necessary for efficient growth and development of young bats (Tuttle, 1975; 1976*a*).

Because relatively few caves serve as maternity roosts (Rice, 1957), a reduction in the availability of maternity caves could lead to declines in the southeastern myotis population in Florida. Rice (1957) provided a baseline assessment of the number of southeastern myotis maternity colonies in Florida caves and several additional colonies have been reported in subsequent years (Bain, 1981; Zinn and Humphrey, 1981; Wenner, 1984). Although no comprehensive survey of maternity caves has been made recently, several former roosts are known to no longer support maternity colonies. For example, landowners have closed the entrances to some former maternity caves and bats have abandoned other maternity caves after being harassed by humans (Wenner, 1984; Humphrey and Gore, 1992). Natural disturbances, such as flooding or rockfalls, may also have contributed to abandonment of maternity caves (Gore and Hovis, 1994). If fewer caves become available to the maternity colonies, a larger portion of the population will be vulnerable to disturbance at individual caves or productivity of the colonies will decrease as less suitable roosts are used. Therefore, protecting the maternity caves is a primary goal in the conservation of the southeastern myotis in Florida.

The objectives of our study were to (1) locate all caves used by southeastern myotis maternity colonies in Florida, (2) compare current and former use of these caves as maternity roosts, and (3) identify threats to the cave roosts and to the reproductive success of the maternity colonies.

METHODS—We searched for maternity roosts in the 2 regions of karst terrain in Florida that contain exposed, horizontal caves suitable for roosting bats (Rice, 1955; Maddox, 1993; Franz et al., 1994). The Panhandle study area encompassed the karst region of northwest Florida along the Chipola and upper Apalachicola rivers in Jackson County; the Peninsula study area included the cavernous portions of northcentral Florida, extending from Columbia County south to Sumter County (Fig. 1). We obtained information on potential maternity caves from published reports and through discussions with biologists, cavers, and landowners. We considered a cave to be a potential maternity roost if bats had been observed in the cave or if the cave had at least a 1-m high entrance or a 1.5-m high ceiling.

Field investigations began in spring 1991 at 15 previously documented maternity caves and 20 potential maternity caves. Additional potential maternity caves were evaluated during the study as they came to our attention. Other potential roosting sites, such as bridges and buildings, were not surveyed because they seldom support large maternity colonies of southeastern myotis (Barbour and Davis, 1969; Jones and Manning; 1989).

We first visited caves between late March and early May and classified as "occupied" those maternity caves in which we found pregnant females. Caves with a record of former use, but no maternity colony in 1991, were labeled "unoccupied." Potentially suitable caves that had no bats during our first visit and no record or evidence of past use were not considered further.

Because several caves contained too many bats to count accurately during the evening emergence, we estimated the number of adult bats in all caves by measuring the surface area of cave ceiling covered by roosting bats (Thomas and LaVal, 1988) and multiplying that figure by 2,000 bats/m^2. This density was derived from the mean of counts we made of roosting bats in 5 sections of the large colony in Sneads Cave ($\bar{x}$ = 2,012; SD = 254.90). To minimize disturbance of the roosting bats, we made a single, annual estimate of bat numbers in each colony prior to birth of the young and inside the caves we used red lights, made minimal sound, and remained <30 minutes near roosting bats.

At each cave we recorded evidence of human disturbance, such as footprints, litter, or graffiti, and we used these data to group the caves. We classified as relatively undisturbed those caves where we found few footprints and where litter or graffiti, if present, was sparse or appeared to be several years old. We considered caves vandalized if footprints were fresh and

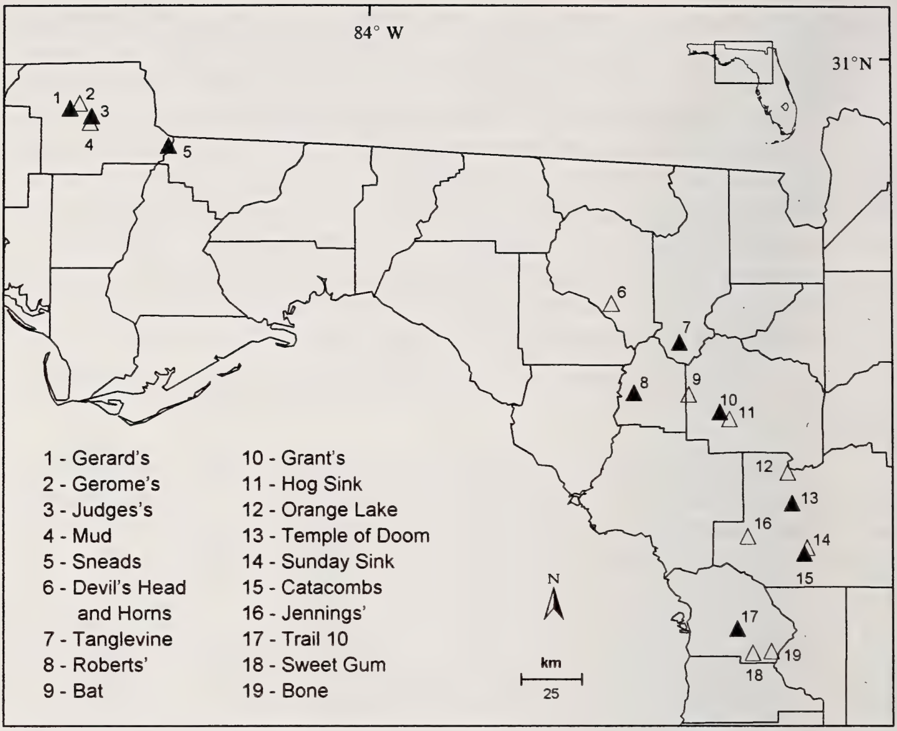


FIG. 1. Location of southeastern myotis maternity caves in Florida that were occupied (▲) or unoccupied (△) by maternity colonies in 1991 and 1992.

numerous and litter or graffiti was recent and abundant. We recorded whether the forest surrounding each cave had been cleared and noted if a cave was no longer accessible to bats because the entrance had been closed, i.e. gated or filled over by the landowner.

We looked for evidence, such as lines of sediment or organic debris on the cave walls, to determine whether the cave entrance or the roost room had been flooded in recent years. If water was present, we estimated the proportion of cave floor that was covered by water and noted whether the colony was roosting over water. We estimated height of all roost rooms and, at 7 occupied caves, we recorded the temperature of the air and cave ceiling. If no bats were present, we searched for ceiling stains, guano, or bat carcasses to confirm former use of the cave by a colony of bats (Tuttle, 1979). Fisher's exact test (Sokal and Rohlf, 1981) was used to determine whether the presence of bats at a cave was significantly associated with water in the cave or disturbance by humans.

We revisited each occupied maternity cave between late June and mid-July 1991 to determine if the colony had produced young. During these visits, we captured bats in a harp trap or hand-held net at dusk as they emerged from the cave and released them after determining sex and age. Maternity colonies with volant young were deemed reproductively successful.

In 1992 we checked for presence of bats as we did in 1991, except that we did not visit Bone Cave, caves with closed entrances, or caves that in 1991 had no bats and no evidence of past use. We made only a single visit to Hog Sink. Also, we made initial visits to potential maternity caves that were first reported to us after July 1991. We counted roosting bats as in 1991, except at 3 caves where access was difficult. To confirm a colony still occupied those caves, we captured emerging bats or relied on recent reports from other observers. We also

TABLE 1. Estimated number of southeastern myotis roosting in maternity colonies in Florida caves in 1991 and 1992 compared to estimates from previous studies.

Region/ County	Cave	This study[a] 1991	This study[a] 1992	Previous studies Estimate	Previous studies Year	Previous studies Source[b]
Panhandle						
Jackson	Gerard's	9,600	7,600	1,000	1970	1
	Gerome's	0	0	15,000	1970	1
	Judge's	15,000	21,600	90,000	1971	1
	Mud	0	0	11,000	1954	2
	Sneads	21,800[c]	85,400	35,000	1970	1
Peninsula						
Alachua	Bat	0	0	2,500	1954	2
	Grant's	13,700[c]	present	90,000	1954	2
	Hog Sink	0	0	30,000	1954	2
Citrus	Bone	0		3,150[c]	1954	2
	Sweet Gum	0	0	64,000	1936	2
	Trail 10	54,000	present			
Columbia	Tanglevine		7,500			
Gilchrist	Roberts'	27,400	19,300	21,600[d]	1978	3
Marion	Catacombs	9,200	present			
	Jennings'	0	0	unknown[e]		4
	Orange Lake	0	0	9,000	1982	5
	Sunday Sink		0	5,000	1976	6
	Temple of Doom	11,500	14,300			
Suwannee	Devil's Head and Horns	0	0	2,500	1953	2

[a] Estimates for 1991 and 1992 were derived by measuring the surface area of cave ceiling covered by roosting adult bats and multiplying that figure by 2,000 bats/m^2. "Present" indicates bats were observed but numbers were not estimated; no visit was made to Sunday Sink or Tanglevine Cave in 1991 or Bone Cave in 1992.

[b] Sources: (1) Wenner, 1984; (2) Rice, 1955; (3) Bain, 1981; (4) Florida Speleological Society, unpublished data; Mansell, 1991; Pike, 1991; (5) Puckett, 1982; (6) Zinn and Humphrey, 1981.

[c] Bats were counted early in the maternity season (late March–early April) and the reported number may greatly underestimate the size of the colony at its peak.

[d] Extrapolated, using a density of 2,000 bats/m^2, from Bain's (1981) estimate of 10.8 m^2 covered by roosting bats.

[e] No historical population estimates are available for Jennings' Cave. However, the cave was used as a maternity roost from the mid 1960's through the early 1980's.

captured bats in June or July of 1992 at all the occupied maternity caves, except Gerard's Cave, to determine if young were produced.

RESULTS—*Roost occupancy*—Fifteen caves in Florida were identified as southeastern myotis maternity roosts prior to our survey (Table 1) and we refer to these as historic roosts regardless of their current status. Seven other caves were previously suggested as possible maternity roosts (Gore and Hovis, 1994), but we found no record that young were ever produced in these caves and we did not include them as historic roosts.

We found pregnant adult females roosting in 8 caves in 1991 and 9 caves in 1992 (Table 1, Fig. 1). We first learned of the maternity colony in Tanglevine Cave in 1992, but bats had been observed in the cave for several

TABLE 2. Disturbances observed and protection enacted at occupied and unoccupied southeastern myotis maternity caves in Florida, 1991 and 1992.

	Disturbance[a]				
Status/Cave	Flooding	Vandalism	Forest cleared	Entrance closed	Protection[b]
Occupied					
Gerard's	—	—	—	—	posted
Grant's	—	—	—	—	posted; fenced
Roberts'	—	—	—	—	none
Judge's	*	—	—	—	posted; fenced
Sneads	*	—	—	—	posted
Tanglevine	*	—	—	—	none
Catacombs	*	+	—	—	none
Trail 10	—	+	—	—	none
Temple of Doom	—	+	—	—	posted
Unoccupied					
Bone	*	—	—	—	none
Gerome's	+	—	+	—	posted
Hog Sink	*	—	+	—	posted
Sunday Sink	*	+	+	—	posted
Bat	*	+	—	—	posted
Orange Lake	*	+	—	—	none
Jennings'	—	+	—	—	posted
Mud	—	—	—	+	
Sweet Gum	—	—	—	+	
Devil's Head and Horns	—	—	—	+	

[a] + disturbance or recent evidence observed during this study; — disturbance not observed or evidence insignificant; * flooding not observed, but water lines on cave walls indicate previous flooding and potential for future flooding.

[b] Actions taken as of 1992 to deter disturbance. Sneads and Trail 10 caves have since been fenced.

years prior to our survey (Sheppard, 1992). Because the reproductive status of the roosting bats was not confirmed in previous years, we did not regard Tanglevine Cave as an historic maternity roost. Five of the 9 occupied caves were historic maternity roosts and 4 were previously undocumented; 10 historic maternity caves were unoccupied in 1991 and 1992 (Table 1).

We observed flooded roosts or evidence of past flooding in 4 of 9 maternity caves that were occupied in 1991 or 1992 and in 6 of 10 unoccupied caves (Table 2). Evidence of flooding was not significantly associated with presence of a maternity colony ($P = 0.308$). Only 3 occupied caves showed signs of vandalism and none had the surrounding forest cleared (Table 2). In contrast, all but 1 of the unoccupied maternity caves had been subjected to some form of human disturbance (Table 2). For the 16 maternity caves still accessible to bats (i.e., those not filled or gated), we found no significant association between vandalism in a cave and the absence of a maternity colony during 1991 or 1992 ($P = 0.615$). However, vandalism was significantly associated with failure of a colony to produce volant young at a cave in 1991 or 1992 ($P = 0.011$). The forest surrounding 3 historic maternity caves had been cleared and none of those caves were occupied by a maternity colony during our survey (Table 2).

In June 1992, we found 3,900 adult females and volant young in Mefford's Cave in Marion County and 3,400 adults and volant young in Sumter County Bat Cave in Sumter County. Because neither cave had a previous record as a bat roost and we first saw the colonies late in the breeding season, we conservatively assumed the bats had moved from nearby maternity roosts.

Reproductive success—In 1991 we found volant young at all 8 occupied maternity caves except Temple of Doom Cave. This cave supported a maternity colony in April, but on 20 June the cave was vacant and we found the remains of a fire directly beneath the empty bat roost.

In 1992, we found pregnant females and no evidence of human disturbance at each of the 3 maternity caves in the Panhandle that were occupied in 1991 (Table 1). We found volant young at Judge's and Sneads caves in June, but we did not visit Gerard's Cave to confirm presence of young. In the Peninsula, of the 6 maternity caves occupied in spring of 1992 (Table 1), only Grant's, Roberts', and Tanglevine caves contained volant young in early summer. Catacombs, Trail 10, and Temple of Doom were vacant by June and showed signs of recent vandalism including spent ammunition alongside carcasses of adult and neonate bats, fresh graffiti, and recent remains of a fire. After a fire was set in Trail 10 Cave, the bat colony moved temporarily to a small cave nearby and returned to Trail 10 later in the summer. Although Sunday Sink was not occupied earlier in the year, volant young were present in June. We suspect the colony from Catacombs moved to Sunday Sink after the young were volant.

Cave characteristics—In 6 of the 9 occupied maternity caves, bats roosted on a relatively smooth, dome-shaped area of ceiling and in 3 caves they roosted in fissures or on uneven ceilings. Bats roosted from 1–6 m ($\bar{x} = 2.7$) above water or the cave floor, and 6 of the roosts were ≤ 2.5 m high. In 7 occupied caves, ceiling surface temperatures ranged from 15.1 to 30.2°C ($\bar{x} = 20.7$); however, only 2 caves had ceiling temperatures >20°C.

Four of the 9 occupied maternity caves had dry floors from the entrance back to the bat roost during our visits. Of the 5 caves with water, none had completely flooded floors and bats roosted directly over water in only 3 of the caves. For the 16 maternity caves with open entrances, we found no significant association between caves with water below the roost and caves occupied by a maternity colony ($P = 0.615$) or caves where volant young were produced ($P = 0.633$).

DISCUSSION—*Number of maternity colonies*—A comparison of our observations and those from earlier studies indicates that the number of occupied maternity caves in the Panhandle declined from 4 or 5 in the 1950's to 3 in 1991 (Table 1). Mud Cave, which was filled in the 1960's, was the only maternity cave that Rice (1955) reported in the Panhandle. However, 3 other Panhandle caves have harbored bats for decades and we assume all have long served as maternity roosts (Gore and Hovis, 1994). The fifth Panhandle site, Gerome's Cave, served as a maternity roost in 1970 (Wenner, 1984), but its status as a regular maternity roost is suspect because the cave usually floods in spring and early summer (J. A. Gore, unpublished data).

The number of occupied maternity caves in the Peninsula declined from at least 8 caves in the 1950's to 6 now (Table 1). The 8 Peninsula caves that were most likely occupied in the 1950's are Jennings' Cave and the 7 caves Rice (1955) found occupied (Table 1). We suspect Orange Lake Cave, Sunday Sink, and the 4 maternity caves newly identified in our survey were not reported by Rice (1955) because they were occupied by a maternity colony only after conditions at a former roost became unsuitable. For example, the maternity colony using Trail 10 Cave may have moved there only after the entrance to nearby Sweet Gum Cave was closed by the landowner in 1989. Similarly, the maternity colony in Tanglevine Cave may have moved there after a nearby maternity cave, Devil's Head and Horns, was closed in the early 1980's.

Due to the paucity of previous observations and the potential for colonies to use alternate caves, we cannot be certain whether any of the 10 unoccupied historic caves and 9 recently occupied caves simultaneously supported maternity colonies in past years. Some of the caves occupied in 1991 and 1992 have apparently been occupied for many years (Table 1), but others may have been occupied only after a colony abandoned another maternity cave. Previous surveys only partially clarify roost histories because even the most extensive survey (Rice, 1955) did not report visits to several caves that now have bats. Given these difficulties, the trends proposed above should be considered minimal declines in the number of occupied maternity caves.

Estimates of colony size—Because no single past survey found more than half of the colonies reported prior to our study, we combined the counts from all past surveys and estimated that about 380,000 southeastern myotis formerly occupied maternity caves in Florida (Table 1). Our estimate for the roosting population in 1991–92 was confounded by premature counts at 2 of the largest roosts, Grant's and Sneads caves, early in the maternity season (late March–early April) before the colonies were at full size. Subsequent observations of roosting or emerging bats at these caves suggested the size of the colonies were much larger than first reported (Gore and Hovis, 1994). Using Rice's (1957) estimate for Grant's Cave and the maximum estimate from 1991 or 1992 for the other caves, we estimated approximately 320,000 adult southeastern myotis (mostly females) roosted in 9 maternity caves during our study (Table 1).

Estimates of the sizes of maternity colonies may be biased greatly due to movements of bats among roosts, variation in roosting density, and errors in measurement of the area of roosting bats. Therefore, comparing our 1991–92 estimate with a composite estimate from previous surveys is of value only as evidence that any decline in bat numbers over the past few decades has not been precipitous. Additional study of population trends would be helpful because the southeastern myotis reproduces slowly and is likely long-lived (Foster et al., 1978; Tuttle and Stevenson, 1982) and, therefore, even annual counts of adults may not detect long-term declines in productivity until adult mortality rates increase and colony size declines.

Abandonment of maternity roosts—Although trends in the size and number of southeastern myotis maternity colonies remain uncertain, southeastern myotis clearly used a different set of caves as maternity roosts in 1991 and 1992 than they did in earlier years (Table 1). One hypothesis to explain the observed change in maternity caves is that the bats periodically move among caves and short-term surveys view only the currently used caves. Without long-term surveys this hypothesis cannot be tested; however, other evidence suggests the bats are not routinely moving among caves before the young are volant.

Because caves are a limited resource, colonial bats are expected to be loyal to their roost caves (Humphrey, 1975). Fidelity to maternity caves should be especially strong because most individuals reproduce successfully only in the select caves that offer suitable microclimatic conditions and sufficient foraging habitat nearby (Rice, 1957; Tuttle, 1975; 1976*a*). Gray myotis (*Myotis grisescens*), for example, use few maternity caves and pregnant females move to alternate caves only rarely and at great risk of reproductive failure (Tuttle, 1976*b,* 1979). Southeastern myotis are similarly loyal to their maternity roosts. Rice (1957) banded nearly 2,000 individuals at maternity caves and recovered only 0.2% in other caves. Strong site fidelity and potentially high reproductive costs of changing roosts suggest that southeastern myotis maternity colonies now use fewer caves or less productive caves than they did a few decades earlier and do not readily move among caves each year.

If southeastern myotis are not routinely shifting among maternity caves, changes at their former roost caves must be prompting the colonies to move to new caves. Rice (1957) concluded that southeastern myotis required maternity caves with roosts located over water, and he speculated that bats abandoned caves when water levels dropped and exposed a dry cave floor beneath the bat roost. Conversely, changes in local hydrology might lead to increased flooding of some maternity caves and their subsequent abandonment by roosting bats. More than half of the maternity caves we surveyed showed signs of being flooded in recent years. However, neither evidence of past flooding nor absence of water beneath the roost was significantly associated with presence of a maternity colony. Rockfalls are even less likely to influence the movement of bat colonies, at least not over a matter of decades. We observed remains from the breakdown of ceiling material at several caves, but we found no evidence that ceiling collapses destroyed roosting sites in any maternity cave.

Disturbance by humans may account for most of the observed changes in roosting locations. Landowners have deliberately filled or sealed entrances to at least 3 former maternity caves in recent decades (Table 2), thus preventing use of the caves by bats. In addition, repeated or intense disturbance of roosting bats within the caves, particularly prior to parturition, can cause a maternity colony to abandon a preferred roost for another (Tuttle, 1975; 1979). We suspect that frequent human visits and vandalism at Bat, Jennings', Orange Lake, and Sunday Sink caves have largely precluded recent use by roosting bats. Among caves occupied by maternity colonies, bats abandoned their roosts before the young were volant only in the 3 caves that were flagrantly vandalized (Table 2). Even relatively unintrusive visits into a maternity cave, if frequent, may be as harmful as single acts of vandalism. Furthermore, indirect disturbance, such as clearing adjacent forest, can alter foraging patterns or increase predation on cave-roosting bats (Tuttle, 1979). Forests had been cleared around 3 southeastern myotis maternity caves prior to our study and bats were absent from all 3 caves (Table 2).

Proving that human disturbance causes a decline in the number or productivity of southeastern myotis colonies will be difficult; therefore, some conservation efforts should be enacted based upon the evidence available. To prevent the further loss of maternity roosts in Florida caves or the decline in the colonies' reproductive success, efforts to limit inadvertent and malicious disturbance of maternity caves need to be more strongly promoted by cavers, landowners, and resource managers. Roost caves are protected most effectively through some combination of restricting access and informing potential visitors about the bats (Tuttle, 1979; Sheffield et al., 1992). Informative warning signs and fencing reduce disturbance at several Florida caves and these measures should be considered for all caves where vandalism has been a problem, including those no longer occupied by bats (Table 2). Recreational exploration of maternity caves should be prohibited between 15 February and 15 August, the period when maternity colonies are usually present. Because disturbance levels can change markedly when land ownership changes, extended protection of caves is important and public acquisition or deed restrictions should be sought for all bat maternity caves in Florida.

ACKNOWLEDGMENTS—We thank the many landowners who kindly allowed us to visit caves on their property. We also gratefully acknowledge the advice and assistance of many cavers throughout the state. Special thanks are extended to A. Allgaier, W. W. Baker, D. Clark, R. Franz, S. R. Humphrey, A. A. Krause, B. Mansell, P. E. Moler, W. H. Oldacre, L. D. Pike, M. A. Sheppard, M. D. Tuttle, and T. L. Zinn for providing useful information about the location and history of caves and bat colonies. We also thank the many individuals who assisted us in the field, especially W. W. Baker, S. I. Cerulean, C. M. Florko, L. M. Howell, S. F. Husted, P. G. R. Jodice, C. C. Long, C. S. Marks, G. E. Marks, L. D. Pike, S. R. Schulze, M. A. Sheppard, and P. J. Strow. B. A. Cerauskis helped prepare the figure. T. J. Doonan, B. A. Millsap, T. E. O'Meara, and V. Heller provided helpful comments on an earlier draft of the manuscript. Funding for this study was provided through Florida's Nongame Wildlife Trust Fund.

LITERATURE CITED

BAIN, J. R. 1981. Roosting ecology of three Florida bats: *Nycticeius humeralis, Myotis austroriparius,* and *Tadarida brasiliensis.* M.S. Thesis. University of Florida, Gainesville, Florida. 131 pp.

BARBOUR, R. W. AND W. H. DAVIS. 1969. Bats of America. University Press of Kentucky, Lexington, Kentucky. 286 pp.

FOSTER, G. W., S. R. HUMPHREY, AND P. P. HUMPHREY. 1978. Survival rate of young southeastern brown bats, *Myotis austroriparius,* in Florida. J. Mammal. 59:299–304.

FRANZ, R., J. BAUER, AND T. MORRIS. 1994. Review of biologically significant caves and their faunas in Florida and south Georgia. Brimleyana 20:1–109.

GORE, J. A. AND J. A. HOVIS. 1994. Southeastern myotis maternity cave survey. Final Performance Report, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida. 33 pp.

HUMPHREY, S. R. 1975. Nursery roosts and community diversity of nearctic bats. J. Mammal. 56:321–346.

——— AND J. A. GORE. 1992. Southeastern brown bat. Pp. 335–342. *In*: HUMPHREY, S. R. (ed.). Rare and Endangered Biota of Florida, Volume 1. Mammals. University of Florida, Gainesville, Florida.

JONES, C. AND R. W. MANNING. 1989. *Myotis austroriparius.* Mammal. Species 332:1–3.

MADDOX, G. L. 1993. Karst features of Florida Caverns State Park and Falling Waters State Recreation Area; Jackson and Washington counties, Florida. Southeastern Geol. Soc. Guidebook 34:1–38.

MANSELL, B. 1991. Jacksonville, Florida. Pers. Commun.

PIKE, L. D. 1991. Tampa Bay Area Grotto, National Speleological Society, Tampa, Florida. Pers. Commun.

PUCKETT, C. 1982. Intrusions by people threaten Florida bats. The Gainesville Sun, 25 July: E-1.

RICE, D. W. 1955. Life history and ecology of *Myotis austroriparius.* M.S. Thesis. University of Florida, Gainesville, Florida. 74 pp.

———. 1957. Life history and ecology of *Myotis austroriparius* in Florida. J. Mammal. 38: 15–32.

SHEFFIELD, S. R., J. H. SHAW, G. A. HEIDT, AND L. R. MCCLENAGHAN. 1992. Guidelines for the protection of bat roosts. J. Mammal. 73:707–710.

SHEPPARD, M. A. 1992. Volunteer, Florida Game and Fresh Water Fish Commission, Ocala, Florida. Pers. Commun.

SOKAL, R. R. AND F. J. ROHLF. 1981. Biometry, 2nd ed. W. H. Freeman and Company, New York, New York. 859 pp.

THOMAS, D. W. AND R. K. LAVAL. 1988. Survey and census methods. Pp. 77–89. *In*: KUNZ,T. R. (ed.). Ecological and Behavioral Methods for the Study of Bats. Smithsonian Institution Press, Washington, D.C.

TUTTLE, M. D. 1975. Population ecology of the gray bat (*Myotis grisescens*): factors influencing early growth and development. Univ. Kansas, Occas. Papers Mus. Natur. Hist. 36:1–24.

———. 1976*a*. Population ecology of the gray bat (*Myotis grisescens*): factors influencing growth and survival of newly volant young. Ecology 57:587–595.

———. 1976*b*. Population ecology of the gray bat (*Myotis grisescens*): philopatry, timing and patterns of movement, weight loss during migration, and seasonal adaptive strategies. Univ. Kansas, Occas. Papers Mus. Natur. Hist. 54:1– 38.

———. 1979. Status, causes of decline, and management of endangered gray bats. J. Wildl. Manage. 43:1–17.

——— AND D. E. STEVENSON. 1982. Growth and survival of bats. Pp. 105–150. *In*: KUNZ, T.

H. (ed.). Ecological and Behavioral Methods for the Study of Bats. Smithsonian Institution Press, Washington, D.C.

WENNER, A. S. 1984. Current status and management of gray bat caves in Jackson County, Florida. Florida Field Natur. 12:1– 6.

ZINN, T. L. AND S. R. HUMPHREY. 1981. Seasonal food resources and prey selection of the southeastern brown bat (*Myotis austroriparius*) in Florida. Florida Scient. 44:81–90.

Florida Scient. 61(3/4): 160–170. 1998
Accepted: January 20, 1998

ACKNOWLEDGMENT OF REVIEWERS

It is a pleasure to acknowledge the cooperation, dedication, expertise, and professional service rendered by the following persons, who generously contributed time in expertise in reviewing manuscripts for Volume 61. Some graciously reviewed more than one manuscript.

Donald Anderson
R. S. Braman
Mark Brown
Bruce J. Cochrane
Susan Cook
Patricia M. Dooris
Richard Hammerschlag
Christine V. Hawkes
William H. Kern, Jr.
Kenneth Langeland
James Layne
G. Michael Lloyd
Dean F. Martin
D. Bruce Means
Walter Meshaka, Jr.
Henry R. Mushinsky
Ron Myers
Jan Pechenik
John Reynolds III
Paul A. Schmalzer
Frank Schwartz
William H. Taft
David Yeager
Richard P. Wain
Richard P. Wunderlin

LAND USE AND LAND COVER TRENDS IN FLORIDA 1936–1995

RANDY S. KAUTZ

Florida Game and Fresh Water Fish Commission,
620 S. Meridian Street, Tallahassee, FL 32399-1600

ABSTRACT: *Between 1936 and 1995, Florida's population grew from 1.7 million to 14.1 million residents. Over this period, forests declined 22%, herbaceous wetlands declined 51%, agricultural lands increased 60%, and urban lands increased 632%. However, since 1980, herbaceous wetlands have been increasing, and agricultural lands have been decreasing. In 1936, pine forests dominated forest lands, longleaf pine was the most abundant tree, 37% of forests were in sawtimber, and 14% of forest land was clearcut. By 1949, extensive logging of longleaf and old-growth pines left 51% of the state's forest land in a nonstocked condition, and sawtimber comprised only 17% of the forest. By 1995, longleaf pine forests had declined by 90%, slash pines were the most dominant tree, only 3% of forest lands were nonstocked, and pine plantations accounted for 32% of all forests. Based on observed trends, pond pine and scrub oak forests could become scarce on privately-owned commercial forest lands by 2010, longleaf pine forests could become rare on privately-owned commercial forest lands by 2019, and natural pine forests could disappear from all commercial forest lands by 2021.*

SINCE 1936, the U.S. Forest Service (USFS) has conducted periodic inventories of forest resources and major land uses in Florida as part of the nationwide Forest Inventory and Assessment (FIA) program. Kautz (1993) used FIA data to report land use trends between 1936 and 1987. Using forest types and land use trends as indicators of wildlife habitat, Kautz (1993) then interpreted land use trends in terms of effects on wildlife and wildlife habitat in Florida during the study period.

The purpose of this paper is to update the results reported by Kautz (1993) using FIA data collected between June 1993 and May 1995, and reported by Brown (1996). This paper also presents a reanalysis of some of the earlier data appearing in Kautz (1993).

METHODS—Between 1936 and 1995, the USFS conducted seven systematic inventories of forest resources in Florida. The results of these inventories appear in a series of USFS technical reports (Eldredge, 1938a, 1938b; Ineson and Eldredge, 1938; McCormack, 1950; Larson and Goforth, 1961; Knight and McClure, 1971; Bechtold and Knight, 1982; Brown and Thompson, 1988; Bechtold et al., 1990; Brown, 1996). The data in these reports were collected using a combination of field survey and aerial photo interpretation techniques.

Land use and forest type data indicative of the changing status of wildlife habitat in Florida were extracted from the USFS reports (Tables 1 and 2) and analyzed for trends. Additional unpublished data obtained from the USFS Southern Research Station in Asheville, NC, were

TABLE 1. Data used to describe trends in land use and land cover in Florida between 1936 and 1995.

	1936	1949	1959	1970	1980	1987	1995
Population	1,725,700	2,683,900	4,733,500	6,791,400	9,740,000	12,042,800	14,149,300
Land use (ha)							
Forest	8,490,000	8,468,300	7,567,600	7,263,600	6,959,800	6,722,300	6,613,500
Marsh	2,807,100	2,400,200	2,454,000	1,476,900	1,229,500	1,251,300	1,378,800
Agriculture/range	2,437,100	2,726,100	3,286,000	4,128,100	4,377,200	4,168,200	3,890,400
Urban/other	292,900	432,600	719,600	1,158,500	1,460,600	1,885,200	2,144,500
Total area	14,027,100	14,027,100	14,027,100	14,027,100	14,027,100	14,027,100	14,027,200
Commercial vs. noncommercial forest lands (ha)							
Commercial	7,672,000	7,639,400	6,813,600	6,574,500	6,362,800	6,086,100	5,973,200
Noncommercial	818,000	828,900	754,000	689,100	597,000	636,300	640,300
Total forest	8,490,000	8,468,300	7,567,600	7,263,600	6,959,800	6,722,300	6,613,500
Commercial pine forests (ha)							
Longleaf pine	3,171,900	2,601,600	1,323,300	620,400	504,800	386,300	301,900
Slash pine	1,999,600	1,921,800	1,600,700	2,197,300	2,151,900	2,111,900	2,091,900
Loblolly pine	239,700	272,500	148,800	139,500	167,200	235,000	329,200
Sand pine	164,800	155,500	170,000	204,900	218,300	247,900	258,400
Pond pine	118,600	157,900	139,900	139,200	94,700	64,100	44,200
Total pine	5,694,600	5,109,300	3,398,400	3,272,100	3,156,000	3,057,400	3,032,400
Commercial hardwood forests (ha)							
Oak-pine	285,400	—	367,400	676,100	578,500	491,800	603,000
Oak-hickory	260,900	296,100	432,200	389,800	459,200	428,100	586,200
Scrub oak	639,500	770,900	787,400	542,300	407,300	339,800	234,600
Total upland	1,185,900	1,067,000	1,587,000	1,608,100	1,445,000	1,259,700	1,423,800
Lowland	791,500	1,463,100	1,828,200	1,642,500	1,761,800	1,769,000	1,516,900
Total hardwood	1,977,400	2,530,100	3,415,200	3,250,600	3,206,800	3,028,700	2,940,700
Cropland and pasture/rangeland (ha)							
Cropland	—	—	1,426,600	1,495,500	1,537,300	1,599,300	1,474,400
Pasture/range	—	—	1,859,400	2,632,600	2,840,000	2,568,900	2,416,000
Total agriculture	2,437,100	2,726,100	3,286,000	4,128,100	4,377,200	4,168,200	3,890,400

TABLE 2. Data used to define trends in forest stand-size classes, pine plantations, and forest ownership 1936–1995.

	1936	1949	1959	1970	1980	1987	1995
Pine forests: stand-size class (ha)							
Sawtimber	1,746,300	713,900	—	778,100	—	742,000	674,600
Poletimber	2,028,200	979,100	—	921,400	—	943,100	993,700
Sapling-seedling	537,700	643,600	—	1,308,800	—	1,177,700	1,256,700
Nonstocked	1,129,500	2,593,100	—	263,700	—	183,900	107,400
Hardwood forests: stand-size class (ha)							
Sawtimber	959,300	601,600	—	1,210,600	—	1,252,200	1,276,900
Poletimber	909,500	457,100	—	733,700	—	628,600	647,000
Sapling-seedling	132,000	290,300	—	497,100	—	604,100	949,900
Nonstocked	31,900	1,303,200	—	758,600	—	533,200	67,000
All commercial forests: stand-size class (ha)							
Sawtimber	2,789,900	1,315,500	—	1,988,800	2,017,200	1,994,200	1,951,600
Poletimber	3,017,700	1,436,200	—	1,655,100	1,673,500	1,571,700	1,640,600
Sapling-seedling	681,300	933,900	—	1,805,900	1,855,200	1,781,700	2,206,600
Nonstocked	1,164,200	3,896,300	—	1,022,200	816,900	717,100	174,400
Natural vs. planted pine forests (ha)							
Pine plantation	—	—	—	1,014,500	1,333,200	1,629,600	1,889,200
Natural pine	—	—	—	2,257,600	1,822,800	1,417,100	1,143,200
Ownership (ha)							
National forest	—	417,200	413,800	412,800	408,500	400,800	419,700
Other public	—	502,300	479,600	442,700	476,200	588,100	734,800
Industry	—	—	1,816,900	2,080,000	1,907,900	1,930,700	1,637,100

also used in the analyses. Definitions for the major land use, land cover, and forest types appearing in the USFS inventories can be found in Brown (1996).

Several minor corrections were made to the USFS data reported herein. First, each of the USFS reports contains a different estimate of the total land area of the state. The land area estimates are provided to the USFS by the U.S. Bureau of Census. The USFS uses total land area estimates as the basis for developing statewide estimates of land use and forest types from the sample data collected during each inventory. In an effort to ensure that the results reported here were consistent over time, all of the land use and forest type data in each report were normalized to 14,127,100 ha, the figure reported by Anderson and Fernald (1981) as the total land area of Florida.

Second, Knight and McClure (1971) point out that 0.9 million ha of Florida classified as forest land in the 1936, 1949, and 1959 surveys were reclassified to natural rangeland in the 1970 survey. The reclassified lands, which have "practically no timber or evidence of reproduction" (Knight and McClure, 1971), were in the central (0.7 million ha) and south (0.2 million ha) Florida survey units. Although Knight and McClure (1971) are not specific on the point, it appears that the reclassified lands are the prairies of central and south Florida. Prairies are recognized as a distinct type of natural plant community that Abrahamson and Hartnett (1990) characterize as treeless savannahs dominated by saw palmetto (*Seronoa repens*) and native grasses and forbs. Subsequent USFS surveys in 1980, 1987, and 1995 also considered the treeless savannahs of south and central Florida as native rangeland, not forest lands. To account for the reclassification and to more accurately reflect the area of forest land in the state during the earlier surveys, normalized estimates of the 0.9 million ha of reclassified lands were subtracted from the forest land category and added to the agriculture and rangeland category for the area estimates reported for the 1936, 1949, and 1959 surveys.

Third, the reclassification of 0.9 million ha from the forest land to the rangeland category in 1970 made it necessary to also subtract 0.9 million ha from the appropriate forest types in the first three surveys in order to more accurately portray long-term trends among forest types. Unfortunately, the USFS report for the 1970 survey (Knight and McClure, 1971) gives no information useful for determining which forest types were affected by the reclassification. Abrahamson and Hartnett (1990) cite a number of authors who have noted that Florida prairies hardly differ from pine flatwoods except in the absence of pine trees. A review of the range maps of Florida trees appearing in Little (1978) and habitat descriptions appearing in Burns and Honkala (1990) indicates that, of the seven species of pines naturally occurring in Florida, only longleaf pine (*Pinus palustris*) and slash pine (*P. elliottii*) have distributions that encompass most of the prairie regions of central and south Florida. While today the flatwoods of central and south Florida are dominated by slash pines, that was not necessarily the case historically as longleaf pine was once the most abundant species of pine in the state. In order to determine the relative proportions of longleaf and slash pines likely to occur on Florida prairies (if they occurred there at all), I first digitized the range maps for both longleaf pine and slash pine. Then, I overlaid the two range maps on a digitized map of Florida prairies as depicted by Davis (1967). This technique showed that longleaf pine alone could have covered 35% of prairies, slash pine alone could have covered 39% of prairies, and longleaf and slash pine in combination could have covered 26% of prairies. Assuming that longleaf and slash pine occurred in equal numbers in the area where they occurred in combination, I estimated that 47.74% of prairies would have been dominated by longleaf pine and 52.26% would have been covered by slash pine. Applying these estimates to the 0.9 million ha of forest land reclassified as rangeland, 0.43 million ha was subtracted from the normalized area estimates for longleaf pine forests, and 0.47 million ha was subtracted from the normalized area estimates for slash pine in the 1936, 1949, and 1959 surveys.

Fourth, Knight and McClure (1971) also point out that 0.18 million ha classified as commercial forest land in the 1936, 1949, and 1959 surveys were reclassified as unproductive forest in the 1970 survey. Therefore, I subtracted 0.18 million ha from the area of commercial forest land and added that amount to the unproductive forest category in the three early surveys. All of the areas reclassified from productive to unproductive forest were in the south Florida region, an area dominated by flatwoods and wetlands. Based on sketchy information in the USFS reports, knowledge of the habitats in the region, and comments made by an anonymous reviewer, I assume that areas reclassified from productive to unproductive forest land probably were forested wetlands dominated by cypress (*Taxodium ascendens*) and blackgum (*Nyssa biflora*). Therefore, 0.18 million ha was subtracted from the area estimates for lowland hardwood forests in the 1936, 1949, and 1959 surveys.

Fifth, the USFS separated marsh lands (i.e., herbaceous wetlands) from other cover types in all but the 1936 survey, at which time marsh lands were lumped with the "urban and other lands" class. To estimate the area of marsh lands present in Florida in 1936, I developed a linear regression equation to predict the area of "urban and other lands" using the size of the human population in the 1949–1987 surveys. The resulting equation ($r^2 = 0.99$, $p \leq 0.01$) was used to estimate the area of "urban and other lands" in 1936 using the estimated size of the Florida population at that time. The area of marsh lands in Florida in 1936 was calculated as the difference between the known area of the marsh/urban/other class and the estimated area of the urban/other class.

Finally, the 1936 survey actually consists of three separate reports covering the northeast (Eldredge, 1938a), the northwest (Eldredge, 1938b), and the central and south Florida regions (Ineson and Eldredge, 1938). Of the three reports, only the northeast Florida region report contains comprehensive data on forest resources by forest type. The data reported for the northwest, central, and south Florida regions were much more general. In order to develop more detailed estimates of the area of the state occupied by each major forest type in 1936, I made two separate assumptions. First, I assumed that the relative proportions of longleaf and slash pine in northeast Florida in 1936 could be used to estimate longleaf and slash pine area in northwest Florida in 1936 due to the physiographic and climatic similarities of the regions and the complete overlap of the ranges of these two species in these regions of the state. Second, the relative proportions of other forest types statewide, and for longleaf pine and slash pine in the central and south Florida regions, could better be estimated from information found in later surveys. The next survey with information sufficiently detailed for such estimates was in 1959. Therefore, the figures reported for longleaf pine and slash pine forest area in northwest Florida in 1936 are estimated from the relative proportions of these two species appearing in the 1936 USFS survey report for northeast Florida. The figures reported for longleaf and slash pine in the central and south Florida regions for 1936, and for all other forest types statewide in 1936, were estimated from the relative proportions of major forest types appearing in Larson and Goforth (1961) for the 1959 survey.

RESULTS—*Land use and land cover 1936–1995—Forest land*—In 1936, forest land covered 8.49 million ha (60%) of the land area of Florida (Figure 1). Although the area of forest land remained relatively constant between 1936 and 1949, Florida's forests have declined steadily since 1949 (Figure 2a). By 1995, forest lands covered 6.61 million ha (47%) of Florida.

Marshes—In 1936, marshes covered 2.81 million ha (20%) of Florida (Figure 1). Marsh area declined between 1936 and 1949, remained relatively constant between 1949 and 1959, and then declined sharply between 1959 and 1980 (Figure 2b). Since 1980, marsh area has increased by 0.15 million ha, and by 1995 marshes covered 1.38 million ha (10%) of Florida. Despite the slight upturn in marsh area in the last few years, 1.45 million ha of marsh land were lost between 1936 and 1995, a loss of 51%.

Agriculture and rangeland—In 1936, agriculture and rangeland covered 2.44 million ha (17%) of Florida (Figure 1). Conversion of natural areas to

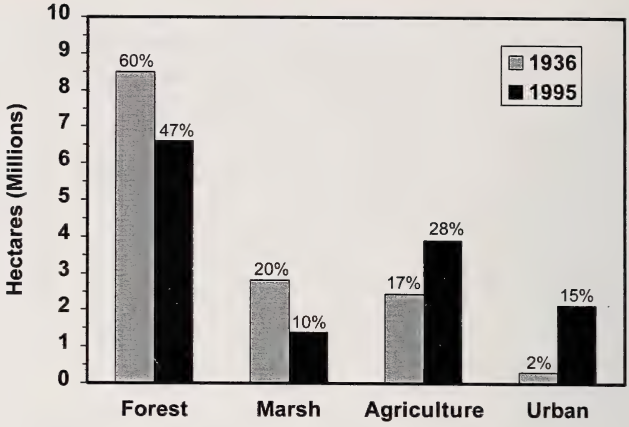


FIG. 1. Overall changes in land cover and land use in Florida between 1936 and 1995. The figures above each bar are percentage of the total land area of the state.

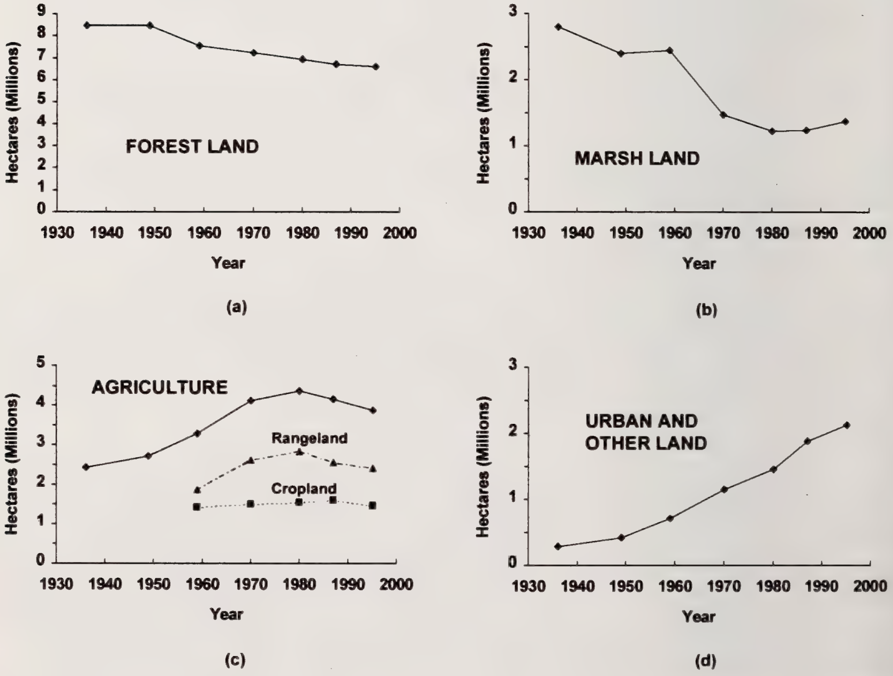


FIG. 2. Land area trends for (a) forests, (b) marshes [i.e., herbaceous wetlands], (c) agriculture [including rangeland and cropland], and (d) urban and other lands in Florida during the 59 year period from 1936 to 1995.

agricultural and rangeland uses increased to a peak of 4.38 million ha (31% of the land area) in 1980 (Figure 2c). Since 1980, agriculture and rangeland area has declined to 3.89 million ha (28% of the state), a loss of 0.49 million ha over a 15 year period.

Beginning with the 1959 survey, USFS began to report separate statistics for cropland and rangeland. During the survey period from 1959 through 1995, rangeland comprised 57 to 65% of the agricultural land category. Between 1959 and 1987, cropland area increased only slightly from 1.43 to 1.60 million ha, but by 1995 cropland area had fallen to 1.47 million ha (10% of the state). Between 1959 and 1980, rangeland area increased 53% to 2.84 million ha. However, from 1980 through 1995, rangeland area declined to 2.42 million ha (17% of the state).

Urban and other lands—In 1936, urban and other lands covered 0.29 million ha (2%) of the land area of Florida. Urban and other lands increased steadily during the study period, covering 2.14 million ha (15%) of Florida in 1995 (Figure 2d).

Forest lands 1936–1995—The USFS collects detailed forest stand information only on forests growing on sites defined as commercial lands, or lands capable of producing 0.23 m^3/ha/yr of industrial wood and not withdrawn from production. Therefore, the following detailed discussions of forests trends pertain only to forests growing on commercial sites. Noncommercial forests are defined as those growing on unproductive sites (e.g., mangrove swamp, scrub cypress) or on lands reserved from timber production (e.g., state parks). Detailed trend data on noncommercial forests are not available.

Commercial and noncommercial forests—Lands covered by commercial forests accounted for 90% of all forest land during the 59 year study period (Figure 3a). Commercial forest area declined from 7.67 million ha (55% of the state) in 1936 to 5.97 million ha (43%) in 1995. Noncommercial forest area declined from 0.82 million ha (6% of the state) in 1936 to 0.64 million ha (5%) in 1995.

Pine and hardwood forests—In 1936, pine-dominated forests on commercial sites covered 5.69 million ha (41% of the land area) of the state (Figure 3b). Pine forests on commercial sites declined by 0.59 million ha between 1936 and 1949, but in the 10 years between 1949 and 1959, pine area declined 33% to 3.40 million ha (24% of the state). Since 1970, pine forests on commercial sites have declined gradually, covering 3.03 million ha (22%) of the state in 1995.

In 1936, hardwood forests (including cypress swamps) on commercial sites covered 1.98 million ha (14%) of the state. Between 1936 and 1949, hardwood forest area increased by 0.55 million ha, but between 1949 and

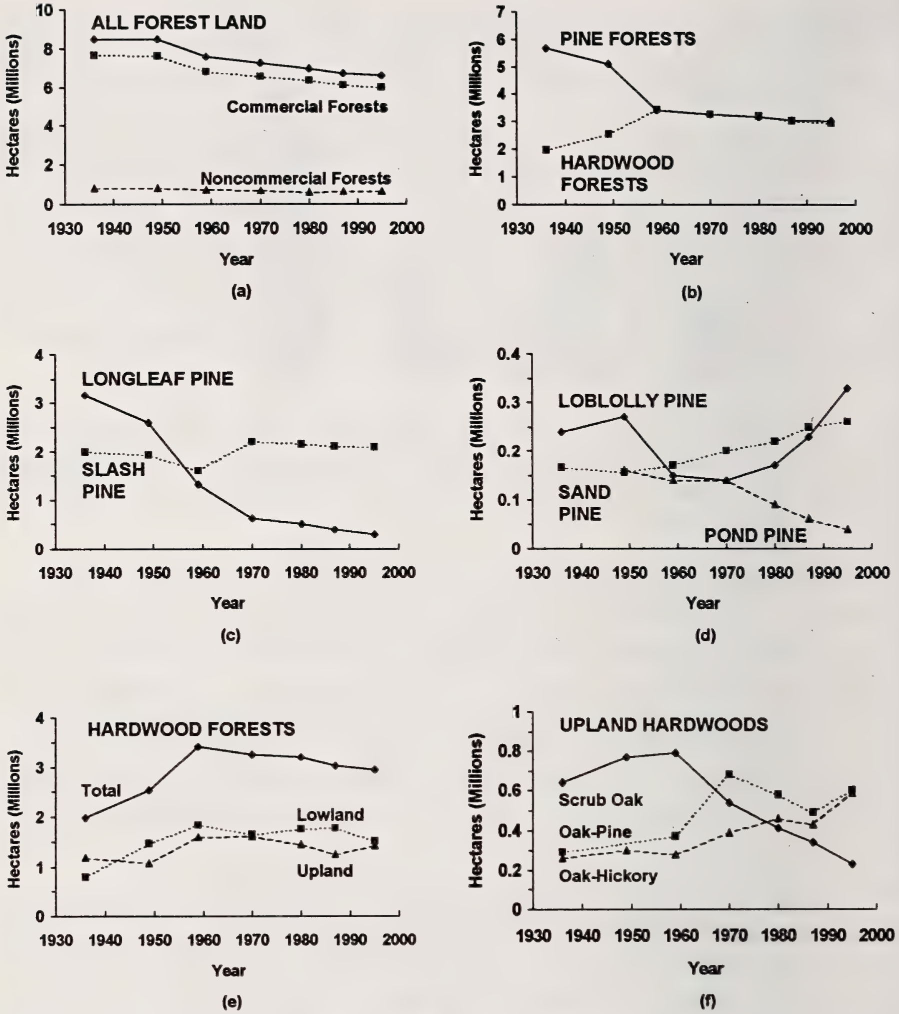


FIG. 3. Trends in land area for (a) all forest lands, including commercial and non-commercial forests, (b) commercial pine and hardwood forests, (c) commercial longleaf and slash pine forests, (d) commercial loblolly pine, sand pine, and pond pine forests, (e) commercial lowland and upland hardwood forests, and (f) commercial scrub oak, oak-pine, and oak-hickory forests in Florida between 1936 and 1995.

1959, hardwood forests increased 35% to a peak coverage of 3.42 million ha (24% of the state). Since 1959, hardwood forest area has gradually declined, falling to 2.94 million ha (21% of the state) in 1995. Since 1959, the total area of commercial forest land in the state has been approximately equally distributed between hardwood forests and pine forests.

Longleaf pine and slash pine forests—In 1936, commercial forest lands dominated by longleaf pines covered 3.17 million ha (23%) of the state, and longleaf pine was the most abundant tree species in Florida (Figure 3c). Between 1936 and 1970, longleaf pine forests were cut at a rapid rate. Since 1970, longleaf pine forests have continued to decline, but at a slower pace. By 1995, longleaf pine forests on commercial sites had declined to 0.30 million ha (2% of the land area of Florida). The total area of longleaf pine lost during the study period was 2.87 million ha, a 90% decline over a period of 59 years.

In 1936, slash pine forests on commercial sites covered 2.00 million ha (14%) of Florida. Slash pine forest area decreased to 1.60 million ha between 1936 and 1959, and then increased to a peak coverage of 2.20 million ha (16% of the state) in 1970. Since 1970, the area of slash pine forests has been steadily declining, falling to 2.09 million ha (15% of the state) in 1995.

*Loblolly pine (*P. taeda*), sand pine (*P. clausa*), and pond pine (*P. serotina*) forests*—In 1936, loblolly pine forests on commercial sites were estimated to cover 0.24 million ha (1.7%) of Florida. Between 1936 and 1970, loblolly pine forests declined steadily, reaching a low of 0.14 million ha (1.0% of the state) in 1970 (Figure 3d). Since 1970, loblolly pines increasingly have been planted for commercial timber production such that, by 1995, loblolly pines covered 0.33 million ha of the state, more than at any other time during the 59 year survey period.

In 1936, sand pines on commercial sites were estimated to cover 0.16 million ha (1.2%) of the state. Since then, sand pines have increasingly been planted on former longleaf pine sites, resulting in a steady increase over the study period (Figure 3d). In 1995, sand pines covered 0.26 million ha (1.9%) of the state.

In 1936, pond pines on commercial sites were estimated to cover 0.12 million ha (0.85%) of the state. Between 1936 and 1949, pond pine area increased to 0.16 million ha. Since 1949, pond pine forests have been steadily declining, falling to a low of 0.04 million ha (0.29% of the state) in 1995 (Figure 3d).

Upland hardwood forests—In 1936, upland hardwood forests on commercial sites covered 1.19 million ha (8%) of the land area of Florida and accounted for 60% of all hardwood forests (Figure 3e). Between 1936 and 1949, upland hardwood forests declined by 0.12 million ha, but between 1949 and 1970 upland hardwood area increased sharply, reaching a peak at 1.61 million ha (11% of the state). Between 1970 and 1987, upland hardwood forest area declined 0.35 million ha, but by 1995 upland hardwood forests had again increased to 1.42 million ha (10% of the state), comprising 48% of all hardwood forests and 24% of commercial forest land.

In 1936, scrub oak (*Quercus* spp.) forests (i.e., sandhill sites from which longleaf pines had been logged) were the most abundant type of upland hardwood forests on commercial sites, covering 0.64 million ha (4.6%) of the state. Between 1936 and 1959, scrub oak forests increased to a peak of 0.79 million ha as a result of continued logging of old-growth longleaf pines (Figure 3f). Since 1959, the area of scrub oak forest in the state has steadily declined, falling to 0.23 million ha (1.6% of the state) in 1995.

In 1936, mixed oak-pine forests growing on commercial sites were estimated to cover 0.29 million ha (2.0% of the state). Oak-pine forest area increased slightly between 1936 and 1959, but between 1959 and 1970, oak-pine forests increased sharply, reaching a peak of 0.68 million ha (4.8% of the state). From 1970 to 1987, oak-pine forests declined somewhat, but between 1987 and 1995 oak-pine forests rebounded to 0.60 million ha (4.3% of the state's land area).

In 1936, oak-hickory (*Carya* spp.) forests were estimated to cover 0.26 million ha (1.9%) of the state. Since 1936, the area of oak-hickory forests has steadily increased, reaching a peak coverage of 0.59 million ha (4.2%) in 1995.

Lowland forests—In 1936, lowland forests on commercial sites were estimated to cover 0.79 million ha (5.6%) of Florida and accounted for 40% of all hardwood forests. The area of lowland forests increased steadily between 1936 and 1959, reaching a peak of 1.83 million ha (13%) in 1959 (Figure 3e). Between 1959 and 1987, lowland forest area fluctuated between 1.77–1.83 million ha. Between 1987 and 1995, lowland forests declined to 1.52 million ha (11% of the state), the lowest level observed since 1959. In 1995, lowland forests comprised 52% of all hardwood forests and 25% of all commercial forests.

Size classes of trees 1936–1995—Stand-size class is a classification of forest land based on the diameter class distribution of growing-stock trees in a stand. Sawtimber, poletimber, sapling-seedling, and nonstocked are the four stand-size classes tracked by the USFS.

Commercial forests—In 1936, sawtimber accounted for 36% of all forests, poletimber accounted for 39%, sapling-seedling accounted for 9%, and nonstocked lands accounted for 15% (Figure 4a). The period from 1936 to 1949 was a time of extensive logging, or high-grading, of Florida's forests. By 1949, sawtimber comprised 17% of all forests, poletimber comprised 19%, seedling-sapling comprised 12%, and nonstocked lands comprised 51%. From 1949 to 1970, forests comprised of sawtimber and saplings-seedlings increased significantly while nonstocked areas decreased to below 1936 levels. Between 1970 and 1987, the area of sawtimber, sapling-seedling, and poletimber remained relatively constant while nonstocked areas showed a decreasing trend. Between 1987 and 1995, the area of sawtimber and poletimber remained unchanged, but nonstocked areas showed a marked decrease while sapling-seedling forests showed a marked increase. In 1995,

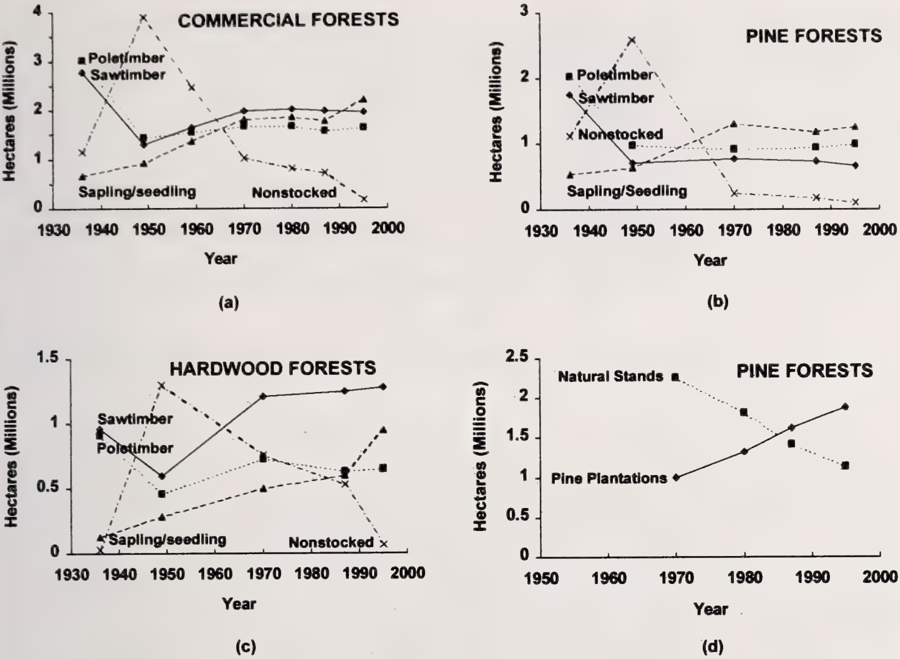


FIG. 4. Land area trends for (a) stand-size classes for all forests on commercial sites, (b) stand-size classes for pine-dominated forests, (c) stand-size classes for hardwood-dominated forests, and (d) pine forests in natural stands versus plantations in Florida between 1936 and 1995.

sawtimber accounted for 33% of all commercial forests, poletimber accounted for 27%, sapling-seedling accounted for 37%, and nonstocked lands accounted for 3%.

Pine forests—In 1936, sawtimber accounted for 32% of pine forests on commercial sites, poletimber accounted for 37%, sapling-seedling pines accounted for 10%, and nonstocked land accounted for 21% of pine forests (Figure 4b). Between 1936 and 1949, pine forests were logged extensively. As a result, in 1949 sawtimber accounted for 14% of pine forests, poletimber accounted for 20%, sapling-seedling accounted for 13%, and clearcut lands accounted for 53% of all pine forests. Between 1949 and 1970, the area of nonstocked pine forests declined dramatically, areas in the sapling-seedling stage increased moderately, and pine forests in sawtimber and poletimber classes remained relatively unchanged. Between 1970 and 1995, pine forests in sawtimber, poletimber, and sapling-seedling stages remained relatively unchanged, but nonstocked lands gradually declined. In 1995, sawtimber accounted for 22% of all commercial pine forests, poletimber accounted for 33%, saplings-seedlings accounted for 42%, and nonstocked lands accounted for 4%.

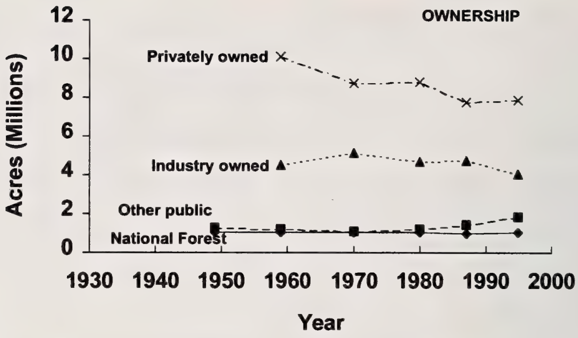


FIG. 5. Ownership trends of commercial forest lands in Florida between 1936 and 1995.

Hardwood forests—In 1936, sawtimber accounted for 47% of hardwood forests on commercial sites, poletimber accounted for 45%, saplings-seedlings accounted for 6%, and nonstocked lands accounted for 2% of hardwood forests (Figure 4c). Extensive logging between 1936 and 1949 also affected hardwood forests. In 1949, sawtimber accounted for 22% of all hardwood forests, poletimber accounted for 17%, saplings- seedlings accounted for 11%, and nonstocked lands accounted for 48%. Since 1949, the area of hardwood forest sites in a nonstocked condition has steadily declined, and between 1987 and 1995 nonstocked hardwood sites declined sharply. Sawtimber area increased markedly between 1949 and 1970, and then increased gradually through 1995. Hardwood poletimber area increased from 1949 to peak extent in 1970, and then declined slightly through 1995. Hardwood forests comprised of saplings-seedlings increased steadily from 1949 through 1987 and then increased sharply between 1987 and 1995. In 1995, sawtimber accounted for 43% of all commercial hardwood forests, poletimber accounted for 22%, saplings-seedlings accounted for 32%, and nonstocked lands accounted for 2%.

Natural vs. planted pines 1970–1995—Data on the area of commercial forest land in pine plantations versus natural pine stands are available only since the 1970 USFS survey (Figure 4d). In 1970, natural stands of pines accounted for 2.26 million ha (69%) of all commercial pine forests, and pine plantations accounted for 1.01 million ha (31%). Between 1970 and 1995, pine forests in a natural condition decreased steadily, and pine plantations increased steadily at the same time that the total area of pine forests decreased by 0.24 million ha. In 1995, natural stands of pines accounted for 1.14 million ha (38%) of all commercial pine forests, and pine plantations accounted for 1.89 million ha (62% of pine forests).

Forest land ownership 1949–1995—Data on ownership patterns for government are only available since 1949 (Figure 5). With respect to government ownership, in 1949, 0.42 million ha of commercial forest land was

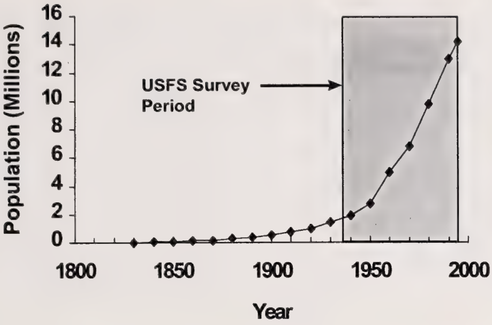


FIG. 6. Human population growth in Florida from the date of the first census in 1830 through 1995.

owned by the USFS, and 0.50 million ha was owned by other government agencies. Between 1949 and 1995, the area of commercial forest land owned by the USFS remained unchanged, but ownership by other agencies of government remained relatively constant from 1949 through 1980. However, since 1980, ownership of commercial forest lands by other government agencies has been increasing, reaching 0.73 million ha in 1995.

Data on overall ownership patterns are available only since 1959. In 1959, privately owned (i.e., not owned by timber industry) lands accounted for 4.10 million ha (60%) of all commercial forest land, timber-industry owned lands accounted for 1.82 million ha (27%), lands owned by the USFS accounted for 0.41 million ha (6%), and lands owned by other agencies of government accounted for 0.48 million ha (7%). Between 1959 and 1987, privately owned commercial forest lands declined 0.95 million ha, but between 1987 and 1995 privately owned forest lands remained relatively unchanged. Between 1959 and 1970, industry-owned lands increased by 0.26 million ha, but since 1970, industry-owned lands have gradually declined, falling to 1.64 million ha in 1995. In 1995, privately owned lands accounted for 3.18 million ha (53%) of all commercial forest lands, industry-owned lands accounted for 1.64 million ha (27%), USFS-owned lands accounted for 0.42 million ha (7%), and commercial forest lands owned by other public agencies accounted for 0.73 million ha (12%).

Population—Between 1830, the date of the first U.S. census in Florida, and 1936, the year of the first USFS forest survey, Florida's population increased very gradually from 34,730 to 1.73 million people (Figure 6). The relatively gradual growth trend continued through 1950. Then, beginning around 1950, Florida's population began to increase at a much faster rate than in the past, and the higher rate of growth persisted through 1995. By 1995, Florida's population was estimated at 14.15 million, and population growth shows no signs of slowing.

TABLE 3. Rates of loss and estimated dates of disappearance for four rapidly declining forest types in Florida.

Forest type	Period of loss	Elapsed time (yr)	Area lost (ha)	Rate (ha/yr)	Years to zero	Zero date
Natural pines	1970–1995	25	1,114,400	44,576	26	2021
Longleaf pine	1970–1995	25	318,500	12,740	24	2019
Scrub oak	1959–1995	36	552,800	15,356	15	2010
Pond pine	1949–1995	46	120,000	2,609	15	2010

Projected disappearance dates for rapidly declining forest types—A quick review of Figures 3 and 4 reveals that longleaf pine forests and natural stands of pine have been declining linearly for 25 years, scrub oak forests have been on a similar decline for 36 years, and pond pine forests have been on a similar decline for 46 years. The rates of loss observed over these periods of relatively linear decline were used to estimate the eventual date of disappearance of these forest types from privately-owned commercial forest lands in Florida (Table 3). Based on observed rates of loss, pond pine and scrub oak forests will no longer occur on privately-owned commercial forest lands in Florida by the year 2010, longleaf pine forests will no longer be found on privately-owned commercial forests by 2019, and all natural pine stands on commercial forest sites will have been converted to pine plantations by 2021.

DISCUSSION—Between 1936 and 1995, the human population of Florida grew from 1.7 million to 14.1 million residents. During the same period, forest land declined 22%, herbaceous wetlands declined 51%, agricultural lands increased 60%, and urban and other lands increased 632%. Despite an overall increase over the 59 year study period, agricultural lands have been on a decreasing trend since 1980, presumably as rangeland and cropland as well as forest lands are converted to urban uses. Somewhat surprisingly, herbaceous wetlands have shown a slight increasing trend since 1980, perhaps due to large scale restoration projects such as those along the Kissimmee River.

In 1936, pine forests dominated Florida forest lands, occupying 74% of the state's commercial forest lands, and longleaf pine was the most abundant tree species (41% of all commercial forest lands). By 1949, extensive logging had left 51% of all commercial forest land without trees and removed 53% of the sawtimber (i.e., larger trees suitable for lumber) from the state's forests. Between 1949 and 1959, logging of pine forests, particularly longleaf pines, continued. By 1959, slash pines were more abundant than longleafs, and hardwood forests occupied a slightly larger area than pine forests. Since 1970, Florida forest lands have been roughly equally divided between pines and hardwoods, longleaf pines continued to be cut, nonstocked lands have been replanted, and pines are increasingly found in plantations.

Today's commercial forests are 32% pine plantations, 25% lowland hardwoods (i.e., forested wetlands), 24% upland hardwoods, and 19% natural stands of pine. Overall, hardwoods account for 65% of the sawtimber in the state, and most (64%) of the state's forests are in the sapling-seedling or poletimber stage, general indicators of the relative youth of the state's forests. The future of Florida's forests are largely in the hands of non- industrial private property owners, who hold title to 53% of all forest lands. The timber industry controls 27% of Florida's forests, and the public owns only 19%.

By 1995, almost all commercial forest land in Florida supported trees. Virtually every hectare of commercial forest land that could support timber for forest industry uses now does so. The only opportunities that exist to increase the area of forest land in Florida would come from conversion of cropland and rangeland to forest uses. However, these lands are not only in demand for agricultural uses, but they also are under increasing pressure for conversion to urban uses. Lacking real opportunities to expand the area of forest land and considering that Florida's population continues to grow, past trends suggest that the area of commercial forest land in Florida will only continue to decline. To maintain a continuing flow of wood products from a decreasing land base, Florida's remaining commercial forest lands will have to become more intensively managed. This means continued conversion of natural stands of pines to plantations, finding new uses for hardwoods, and developing methods for improved access to hardwoods on wetland sites.

The trends identified here point to the continued loss of biological diversity in Florida. Already, 13 vertebrates and 14 vascular plants have been driven to extinction or have been extirpated from Florida (Ward, 1978; Humphrey, 1992; Rodgers et al., 1996), many other species are in danger of extinction or have declining populations (Millsap et al., 1990; Wood, 1996), and several natural community types (e.g., pine rocklands) have almost completely disappeared (Kautz et al., 1993). In less than 25 years, longleaf pine and scrub oak forests (i.e., natural sandhills) are likely to disappear from privately-owned commercial forest lands in the state, and all remaining natural stands of pines on commercial sites will have been converted to pine plantations. In less than 15 years, pond pines will likely no longer occur on privately-owned commercial forest lands. For Floridians who wish to ensure the long-term persistence of the remaining components of the state's biological diversity, the next 15–25 years will be a critical period.

ACKNOWLEDGMENTS—I would like to thank Noel Cost, U.S. Forest Service in Asheville, NC, for providing me with data not available in the standard USFS reports. I also thank Brad

Hartman, Brian Barnett, Carolyn Kindell, and an anonymous reviewer for their comments on previous drafts of the manuscript.

LITERATURE CITED

ABRAHAMSON, W. G., AND D. C. HARTNETT. 1990. Pine flatwoods and dry prairies. Pp. 103–149. *In*: MYERS, R. L., AND J. J. EWEL (eds.), Ecosystems of Florida. University of Central Florida Press, Orlando, FL.

ANDERSON, J. R., JR., AND E. A. FERNALD. 1981. Introduction. Pp. 1–3. *In*: FERNALD, E. A. (ed.), Atlas of Florida. The Florida State University Foundation, Inc., Tallahassee, FL.

BECHTOLD, W. A., AND H. A. KNIGHT. 1982. Florida's forests. U.S.D.A. Forest Service, Southeastern Forest Experiment Station, Resource Bull. SE-62, Asheville, NC. 48 pp.

———, M. J. BROWN, AND R. M. SHEFFIELD. 1990. Florida's forests, 1987. U.S.D.A. Forest Service, Southeastern Forest Experiment Station, Resource Bull. SE-110, Asheville, NC. 83 pp.

BROWN, M. J. 1996. Forest statistics for Florida, 1995. U.S.D.A. Forest Service, Southern Research Station, Resource Bull. SRS-6, Asheville, NC. 48 pp.

BROWN, M. J. AND M. T. THOMPSON. 1988. Forest statistics for Florida, 1987. U.S.D.A. Forest Service, Southeastern Forest Experiment Station, Resource Bull. SE-101, Asheville, NC. 61pp.

BURNS, R. M., AND B. H. HONKALA. 1990. Silvics of North America. Volume 1. Conifers. U.S.D.A. Forest Service, Timber Management Research, Agriculture Handbook 654, Washington, DC. 675 pp.

DAVIS, J. H. 1967. General map of natural vegetation of Florida. Institute of Food and Agricultural Sciences, Agriculture Experiment Stations, Circular S-178, Univ. Florida, Gainesville, FL. 1 p.

ELDREDGE, I. F. 1938a. Forest resources of northwest Florida, a progress report. U.S.D.A. Forest Service, Southern Forest Experiment Station, Forest Survey Release No. 33, New Orleans, LA. 33 pp.

———. 1938b. Forest resources of central and south Florida, a progress report. U.S.D.A. Forest Service, Southern Forest Experiment Station, Forest Survey Release No. 38, New Orleans, LA. 30 pp.

HUMPHREY, S. R (ed.). 1992. Rare and endangered biota of Florida. Volume I. Mammals. University Press of Florida, Gainesville, FL. 392 pp.

INESON, F. A., AND I. F. ELDREDGE. 1938. Forest resources of northeastern Florida. U.S.D.A. Forest Service, Southern Forest Experiment Station, Miscellaneous Publ. No. 313, Washington, D.C. 40 pp.

KAUTZ, R. S. 1993. Trends in Florida wildlife habitat 1936- -1987. Florida Scientist 56(1): 7–24.

———, D. T. GILBERT, AND G. M. MAULDIN. 1993. Vegetative cover in Florida based on 1985–1989 Landsat Thematic Mapper imagery. Florida Scientist 56(3):135–154.

KNIGHT, H. A., AND J. P. MCCLURE. 1971. Florida's timber, 1970. U.S.D.A. Forest Service, Southeastern Forest Experiment Station, Resource Bull. SE-20, Asheville, NC. 48 pp.

LARSON, R. W., AND M. H. GOFORTH. 1961. Florida's timber. U.S.D.A. Forest Service, Southeastern Forest Experiment Station, Forest Survey Release No. 57, Asheville, NC. 32 pp.

LITTLE, E. L. 1978. Atlas of United States trees. Volume 5. Florida. U.S.D.A. Forest Service, Timber Management Research, Miscellaneous Publication No. 1361, Washington, D.C.

MCCORMACK, J. F. 1950. Forest statistics for Florida, 1949. U.S.D.A. Forest Service, Southeastern Forest Experiment Station, Forest Survey Release No. 36, Asheville, NC. 73 pp.

MILLSAP, B. A., J. A. GORE, D. E. RUNDE, AND S. I. CERULEAN. 1990. Setting priorities for the conservation of fish and wildlife species in Florida. Wildl. Monogr. No. 111. 57 pp.

RODGERS, JR., J. A., H. W. KALE, II, AND H. T. SMITH (EDS.). 1996. RARE AND ENDANGERED BIOTA OF FLORIDA. VOLUME V. BIRDS. UNIVERSITY PRESS OF FLORIDA, GAINESVILLE, FL. 688 PP.

WARD, D. B (ED.). 1978. RARE AND ENDANGERED BIOTA OF FLORIDA. VOLUME FIVE. PLANTS. UNIVERSITY PRESSES OF FLORIDA, GAINESVILLE, FL. 175 PP.

WOOD, D. A. 1996. Florida's endangered species, threatened species, and species of special concern official lists. Florida Game and Fresh Water Fish Commission, Tallahassee, FL. 14 pp.

Florida Scient. 61(3/4): 171–187. 1998
Accepted: February 10, 1998

AGE AND GROWTH OF A NEWLY ESTABLISHED WHITE BASS POPULATION IN FLORIDA

JEFFERY J. NORDHAUS(1), BRIAN R. LUBINSKI(2), RICHARD L. CAILTEUX(1), AND DANIEL A. DOBBINS(1)

(1) Florida Game and Fresh Water Fish Commission, Joe Budd Fisheries Field Office, Route 7, Box 3055, Quincy, Florida 32351
(2) Present address: U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Post Office Box 39, Pinetop, Arizona 85935

ABSTRACT: *Age and growth were determined on a newly established white bass (*Morone chrysops*) population in Lake Talquin, Florida from 1984–1993. Back calculated lengths at age were utilized since fish were sampled in the fall, prior to annulus formation. Regression analysis (*$R^2 = 0.67$, $P < 0.001$*) demonstrated a linear relationship existed between fish total length (TL) and the arc sin transform of otolith radius. Age analysis indicated unprecedented growth and recruitment into the fishery (*$\bar{x} = 267$ *mm TL) by age-1. Only 13% of 320 white bass back calculated for age were older than age-3. Mean back calculated lengths at age-1 for all year-classes surpassed published minimum standards deemed as quality size (TL ≥ 230 mm). Differences in length (*$P < 0.0001$*) between males and females was noted as early as age-1. No significant difference (*$P > 0.05$*) in median total length at age-1 was found for all male year-class combinations. A significant difference (*$P < 0.05$*) was apparent for age-2 males in 1984 and 1990. However, all other year-class combinations for age-2 males did not differ significantly (*$P > 0.05$*). Median lengths for all female year-class combinations showed no significant difference (*$P > 0.05$*) at age-1 or -2. A slight, yet significant downward trend (*$R^2 = 0.0879$, $P < 0.01$, $b = -1.005$, $N = 1004$*) in relative weight was present from 1984 (*Wr = 112*) to 1993 (*Wr = 98*). However, relative weights for all sampling years fell within or slightly exceeded the target goal of 100 ± 5. White bass age and growth, for all age-classes, have varied little over its first 10 years. The cyclical nature in year-class strength and the absence of older aged cohorts are likely contributing factors. No white bass (*$N = 1004$*) were ever collected during the course of this study deemed by published standards as trophy size (TL ≥ 460 mm).*

WHITE bass (*Morone chrysops*), native to the Mississippi and Ohio rivers, and the Great Lakes drainage basins, are now prevalent throughout much of the eastern half of the United States. While not native to the southeastern United States, white bass have been successfully introduced into many Southern riverine and reservoir systems (Lee et al., 1980).

This species was commercially important as early as 1830 in Lake Erie (Trautman, 1981). However, today white bass are a favorite among recreational anglers because of their conspicuous schooling activities in lakes and immense spawning runs during the spring. This species is also capable of continuing to support a sportfishery in older reservoirs where other sportfish stocks have declined (Olmstead, 1971; Saul et al., 1982).

In Florida, white bass are only present in two watersheds, the Apalachicola and Ochlockonee Rivers (Lake Talquin). White bass were first collected by gill nets in Lake Talquin in the fall of 1984. Preliminary observations of this newly established species suggested recruitment to harvestable size (TL $\geq$ 230 mm) by age-1. Average length of age-1 white bass from Lake Talquin in 1984 were higher than previously documented values within the United States. First year growth of white bass has been well documented in North and South central portions of its range (Jenkins and Elkin, 1957; Houser and Bryant, 1970; Priegel, 1971; Ruelle, 1971; Yellayi and Kilambi, 1975; Baglin and Hill, 1976; Moen and Dewey, 1980; Muoneke, 1994). However, little information is available on age and long-term growth in its extreme Southeastern range. Age and growth of Lake Talquin white bass were investigated over the course of 10 years (1984–1993) to determine if: (1) the unprecedented first year's growth of each year-class could be sustained over time and/or (2) the exceptional first year's growth in white bass would provide an opportunity for a trophy fishery.

METHODS—The study was conducted on Lake Talquin, a 3,318-ha reservoir located just west of Tallahassee, Florida. Lake Talquin was created in the late 1920s following completion of the Jackson Bluff Hydroelectric Dam on the Ochlockonee River.

White bass were sampled using floating-type experimental gill nets 2.4 m in depth and 45.7 m in length with stretched mesh of 38, 64, 89 and 102 mm. Three gill nets were set at sunset and retrieved at sunrise, a minimum of three times, from November through February for each sampling year. Total length (mm) and weight (g) were recorded for all fish ($N = 1004$) and otoliths (sagittae) removed from every other fish ($N = 479$).

Length and age (otoliths) were collected to determine length after the first full year of growth. White bass were not considered age-1 until March, which is when annulus formation is observed in white bass from Lake Talquin (unpubl. data). Spawning activity also commences during this month. Since, white bass were collected prior to annulus formation (November—February), back calculating the length of older fish to age-1 was required. Of the 479 white bass collected for age analysis, 320 were candidates for back calculating to age-1 (young of year = 159). Only the two most recently formed annuli were used in back calculating a year-classes median length at age to reduce Lee's phenomenon (Gutreuter, 1987).

Otoliths were sectioned (Snyder et al., 1983; Porak et al., 1986) and examined for the presence of opaque bands (Bagenal and Tesch, 1978). Age determination of all white bass otoliths were verified by two separate readers. Otoliths were numbered and then photographed using an Olympus OM-4 camera mounted to the photo tube of an Olympus SZTR stereomicroscope. Doerzbacher and Schramm (1984) reported measurements from photographs offered better precision for back calculation than ocular micrometer measurements. All otoliths were photographed at 5×. Film was developed and 3″ × 5″ standard black and white prints produced. Otolith photographs were sonically digitized (Grafbar, Model GP-9, Science Accessories Corp.) to measure otolith annuli and radius distances. Taubert and Tranquilli (1982) demonstrated otolith radius was not a straight line from the nucleus to dorsal surface, so measurements were made between annuli and accumulative measurements were used as the radius. A computer program utilizing the direct proportion method (Schramm et al., 1992) for back calculating otoliths was adopted from Frie (1982). Total fish length was regressed against otolith radius utilizing arc sin transformed data. This was undertaken to test the basic assumption that as total fish length increased, so did otolith radius.

Relative weights (*Wr*), as described by Anderson and Gutreuter (1983), were regressed by sampling year to reflect changes over time. The length-specific standard weight equation ($\log_{10}$

$Ws = -5.066 + 3.081 \log_{10} TL$) used in calculating *Wr* for white bass was defined by Brown and Murphy (1991).

Analysis of back calculated lengths at age were found to have unequal variances (heteroscedastic). Therefore, a non-parametric Mann-Whitney test was used to compare lengths between males and females to determine if they could be pooled. To determine if differences existed in median year-class lengths between years, a non-parametric all pair wise comparison test (Dunn's post-hoc method) was used to determine significance.

RESULTS AND DISCUSSION—The Lake Talquin white bass fishery is comprised of extremely fast growing but short lived cohorts. White bass in Lake Talquin recruit into the sportfishery ($\bar{x}$ = 267 mm TL) by age-1 (Table 1). However, only 13% of 320 white bass back calculated for age since 1984 were older than age-3. White bass populations in more southern latitudes are usually exemplified as fast growing with shorter life spans (Houser and Bryant, 1970; Moen and Dewey, 1980). Because of this, to determine if changes in median length at age occurred over the course of this study, it will have to be demonstrated utilizing white bass back calculated to age-1 and -2.

Back calculated lengths were not only utilized to increase sample size but also due to the fact that fish were sampled prior to annulus formation. Regression analysis (R^2 = 0.67, $P < 0.001$) demonstrated that back calculating the age of white bass was valid, since a linear relationship did exist between fish total length and the arc sin transform of otolith radius.

Mean back calculated lengths for Lake Talquin white bass at age-1 for all year-classes (Table 1), exceeded Gablehouse's (1984) accepted minimum total length deemed as quality size (230 mm). At age-2, all year-classes surpassed the total length necessary for consideration as preferred size (300 mm). The memorable size category (380 mm) was attained by females at age-3 and males by age-4. No white bass were ever collected during the course of this study (N = 1004) which attained trophy status (460 mm).

A statistical difference ($P < 0.0001$) in median total length at age-1 occurred between males and females (Table 1). As a result, growth rate data from males and females were analyzed separately (Table 1).

No significant difference ($P > 0.05$) in median total length at age-1 was detected for males when utilizing a multiple comparison test for all year-class combinations (Table 1). A significant difference ($P < 0.05$) was apparent for age-2 males when comparing the 1984 and the 1990 year-classes. However, all other year-class combinations for age-2 males were not found to differ significantly ($P > 0.05$).

A multiple comparison test of median total lengths of all possible female year-class combinations showed no significant difference ($P > 0.05$) was present at age-1 or -2.

Mean relative weight (*Wr*) values were determined for each sampling year (Fig. 1). Regression analysis suggested a slight, yet significant downward trend ($R^2 = 0.0879$, $P < 0.001$, $b = -1.005$, $N = 1004$) in *Wr* occurred from 1984 (*Wr* = 112) to 1993 (*Wr* = 98). However, all sampling years fell

TABLE 1. Mean back calculated total length at age for each year class of white bass sampled from Lake Talquin, 1984–1993; parenthetic values = sample size.

	Mean back calculated length (mm) at age								
	Age 1			Age 2			Age 3		
Year class	x̄	S.E.	Median	x̄	S.E.	Median	x̄	S.E.	Median
				Males					
84	282 (5)	3	285	357 (5)	3	353			
86	265 (25)	3	271	341 (25)	3	339			
87	264 (28)	4	269						
90	259 (36)	2	260	332 (16)	4	330	362 (9)	4	362
91	261 (13)	3	263	338 (8)	4	343			
92	287 (1)		287	354 (1)		354			
93	244 (24)	8	238						
x̄ for all years	260 (132)	2		340 (55)	2		362 (9)	4	
				Females					
84	330 (1)		330	400 (1)		400			
86	275 (12)	5	279	357 (12)	4	358			
87	267 (34)	4	267						
90	271 (31)	3	266	357 (31)	3	353	390 (16)	4	395
91	283 (43)	2	287	356 (29)	3	359	386 (9)	3	388
92	315 (2)	8	315						
93	267 (23)	7	281						
x̄ for all years	274 (146)	2		357 (73)	2		389 (25)	3	

within or slightly exceeded the target range for *Wr* of 100 ± 5 (Anderson, 1980).

One could hypothesize that as an introduced population of white bass becomes established, a reduction in the first year's growth would occur over time due to increased competition. Jenkins and Elkin (1957) and Ruelle (1971) reasoned, intraspecific competition was the culprit for declines in white bass growth rates following initial stockings. The age, growth and *Wr* of white bass in Lake Talquin have changed little since their first appearance

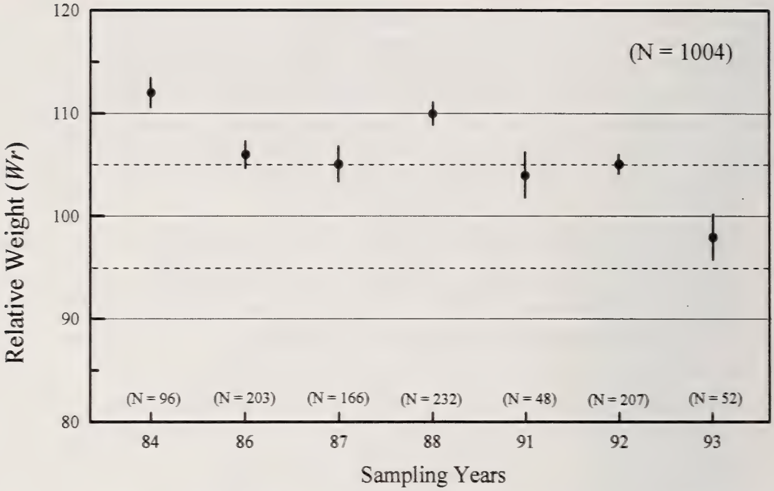


FIG. 1. Relative weight (*WR*) of Lake Talquin white bass for each sampling year 1984–1993 (Illustrated using 95% confidence intervals).

in 1984. Therefore, the effects of intraspecific competition in Lake Talquin is questionable. Explanations for the less than expected change in growth over time may lie in the cyclical nature white bass exhibit. The cyclical nature of this species has been documented when examining year-class strength (Houser and Bryant, 1970; Priegel, 1971). Only 6 individuals were ever aged from the 1984 year-class. The culmination of this newly established population and the existence of few sexually mature 1984 cohorts likely resulted in no individuals being collected from the 1985 year-class. Houser and Bryant (1970) found most males but few females were sexually mature at age-1 in Bull Shoals Reservoir. The 1986 and 1987 year-classes were well represented for age analysis. Only 2 young-of-year were ever aged from the 1988 year-class. No cohorts were ever aged from the 1989 year-class. However, strong year-classes were again prevalent in 1990, 1991 and 1993. The 1992 year-class appeared weak as only 3 cohorts were aged from this year-class.

The apparent low survival of white bass in Lake Talquin past age-3 also helps alleviate intraspecific competition. The absence of older age cohorts may be a function of thermal stress, since Florida represents the extreme southern limits of their range. Coutant (1985) noted another *Morone* species (*Morone saxatilis*) became dependent for its survival on lower water temperatures with increased age. The inaccessibility of cooler thermal refugia to older fish during summer months led to either direct mortality or over exploitation due to congregation in tolerable but limited habitat. Limited cool water thermal refugia in Lake Talquin is suspected in the low survival of *Morone saxatilis* to age 5 (Mesing, 1997).

White bass in Lake Talquin still demonstrate remarkable growth, which has differed little in the ten years following their introduction. The cyclical nature in year-class strength and the presence of few older aged cohorts reduces intraspecific competition and likely influences their tremendous growth rates prior to attaining age-1. White bass collected from the 1993 year-class still exhibited the fastest age-1 growth rates for white bass in the literature. In consideration of all years and gender, Lake Talquin white bass have a mean average length, at age-1 ($\bar{x} = 267$ mm), some 40 mm larger than white bass sampled in a similar latitude by Muoneke (1994) in Texas ($\bar{x} = 224$ mm). Lake Talquin white bass mimic their southern counterparts as fast growing but relatively short lived. The preponderance of the population in this lake was comprised of individuals 3 years and less in age. Although a quality fishery exists, the nature of this fast growing but young fishery does not lend itself currently to providing any trophy potential. Muoneke (1994) achieved modest results from imposing minimum length (TL ≥ 254 mm) and bag limit (25 fish/day) restrictions on an unregulated, heavily exploited lake in Texas. Lake Talquin white bass from 1984–1993 were regulated with a 30 fish bag limit, and no size limit. From 1993 until the present, the daily bag limit has been 20 with no size limit. Before any attempts are made to establish a higher quality or trophy fishery, consideration should be given to determine if the high mortality rate following age-3 is angler induced or natural.

ACKNOWLEDGMENTS—Many thanks are extended to R. Vanderhoof and G. Sprandel for their assistance with statistical analysis. Also, C. Mesing for his helpful review and comments and D. Schroeder for her help in preparing this manuscript.

LITERATURE CITED

ANDERSON, R. O. 1980. Proportional stock density (PSD) and relative weight (Wr): interpretive indices for fish populations and communities. Pp. 27–33. *In*: GLOSS, S. AND SHUPP, B. J. (eds.), Practical Fisheries Management: More with Less in the 1980's. Am. Fish. Soc., New York Chap., Ithaca, New York.

——— AND S. J. GUTREUTER. 1983. Length, weight and associated structural indices. Pp. 283–300. *In:* NIELSEN, L. A. AND JOHNSON, D. L. (eds.), Fisheries Techniques. Am. Fish. Soc., Bethesda, Maryland.

BAGENAL, T. B. AND F. W. TESCH. 1978. Age and growth. Pp. 101–136. *In*: Bagenal, T. B. (ed.), Methods for Assessment of Fish Production in Fresh Waters, third edition. Blackwell Sci. Publ., London.

BAGLIN, R. E., JR. AND L. G. HILL. 1976. Age and growth characteristics of white bass, *Morone chrysops* (Rafinesque), in Lake Texomo, Oklahoma. Oklahoma, Texas J. Sci. 227: 113–124.

BROWN, M. L. AND B. R. MURPHY. 1991. Standard weights (Ws) for striped bass, white bass, and hybrid striped bass. N. Am. J. Fish. Manage. 11:451–467.

COUTANT, C. C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. Trans. Am. Fish. Soc. 114: 31–61.

DOERZBACHER, J. F. AND H. L. SCHRAMM, JR. 1984. Enlarger- produced photographs for the measurement of black crappie otoliths. N. Am. J. Fish. Manage. 4:547–551.

FRIE, R. V. 1982. Measurement of fish scales and back calculation of body lengths using a digitizing pad and micro-computer. Fisheries 7(6):5–8.

GABLEHOUSE, D. W., JR. 1984. A length-categorization system to assess fish stocks. N. Am. J. Fish. Manage. 4:273–285.

GUTREUTER, S. 1987. Considerations for estimation and interpretation of annual growth rates. Pp. 115–126. *In:* SUMMERFELT, R. C. AND HALL, G. E. (eds.), Age and Growth of Fish. Iowa State Univ. Press, Ames.

HOUSER, A. AND H. E. BRYANT. 1970. Age, growth, sex composition, and maturity of white bass in Bull Shoals Reservoir. Bur. Sport Fish. Wildl., South Cent. Reservoir Invest., Fayetteville, Ark., Tech. Paper 49:3–10.

JENKINS, R. M. AND R. E. ELKIN. 1957. Growth of white bass in Oklahoma. Okla. Fish. Res. Lab. Rep. 60:21 pp.

LEE, D. S., C. R. GILBERT, C. H. HOCUTT, R. E. JENKINS, D. E. MCALLISTER, AND J. R. STAUFFER, JR. 1980. Atlas of North American Freshwater Fishes. North Carolina State Mus. Nat. Hist., Raleigh. 867 pp.

MESING, C. L. 1997. Florida Game and Freshwater Fish Comm., Midway, FL, Pers. Commun.

MOEN, T. E. AND M. R. DEWEY. 1980. Growth and year class composition of white bass (*Morone chrysops*) in Degray Lake, Arkansas. Ark. Acad. Sci. Proc. 34:125–126.

MUONEKE, M. I. 1994. Dynamics of a heavily exploited Texas white bass population. N. Am. J. Fish. Manage. 14:415–422.

OLMSTEAD, L. L. 1971. The feeding biology of White Bass, *Roccuss chrysops* (Rafinesque), in Beaver Reservoir, Arkansas. Masters Thesis, Univ. of Ark., Fayetteville, Ark.

PORAK, W. F., W. S. COLEMAN, AND S. M. CRAWFORD. 1986. Age, growth, and mortality of Florida largemouth bass utilizing otoliths. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 40:206–215.

PRIEGEL, G. R. 1971. Age and rate of growth of the white bass in Lake Winnebago, Wisconsin. Trans. Am. Fish. Soc. 3:567–569.

RUELLE, R. 1971. Factors influencing growth of white bass in Lewis and Clarke Lake. Pp. 411–423. *In*: HALL, G. E. (ed.), Reservoir Fisheries and Limnology. Spec. Publ. No. 8, Am. Fish. Soc., Washington, D.C.

SAUL, D. M., J. L. WILSON, D. C. PETERSON, AND J. M. RICHARDSON. 1982. Food habits and growth of young-of-year white bass in two east Tennessee reservoirs. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 36:115–124.

SCHRAMM, H. L. JR., S. P. MALVESTUTO, AND W. A. HUBERT. 1992. Evaluation of procedures for back-calculation of lengths of largemouth bass aged by otoliths. N. Am. J. Fish. Manage. 12:604–608.

SNYDER, L. E., W. K. BORKOWSKI, AND S. P. MCKINNEY. 1983. The use of otoliths for aging morone hybrids. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 37:252–256.

TAUBERT, B. D. AND J. A. TRANQUILLI. 1982. Verification of the formation of annuli in otoliths of largemouth bass. Trans. Am. Fish. Soc. 111:531–534.

TRAUTMAN, M. B. 1981. The fishes of Ohio. Ohio State Univ. Press, Columbus, Ohio. 782pp.

YELLAYI, R. R. AND R. V. KILAMBI. 1975. Population dynamics of white bass in Beaver Reservoir, Arkansas. Proc. Annu. Conf. Southeast. Assoc. of Game and Fish Comm. 29: 172–184.

Florida Scient. 61(3/4): 188–194. 1998
Accepted: March 17, 1998

STUDIES OF THE FLORIDA CONVOLVULACEAE—VI. *DICHONDRA*

—Daniel F. Austin,(1) *Sebsebe Demissew*(2) *and Jill Young*(1), (1)Department of Biological Sciences, Florida Atlantic University, Boca Raton, FL 33431 and (2) The National Herbarium University of Addis Ababa, P.O. Box 3434, Addis Ababa, Ethiopia.

ABSTRACT: *Two species of* Dichondra *are recorded in Florida.* Dichondra carolinensis *is the southeastern U.S. endemic, ranging from Virginia to Texas.* Dichondra micrantha *is reported for the first time in the state. Although* D. micrantha *has been in Florida for over 60 years, it has been confused with the native species. This adventive species has been spread around the world as a lawn weed and grass substitute; it grows in lawns throughout the state.*

THE most recent revision of *Dichondra* recorded only *D. carolinensis* for Florida (Tharp and Johnston, 1961). All subsequent floristic studies of the state have continued that identification of our plants (e.g., Long and Lakela, 1971; Godfrey and Wooten, 1981; Wunderlin, 1982; Clewell, 1982). During our studies of the tribe Dichondreae for Sebsebe's treatment in the Flora of Ethiopia (e.g., Sebsebe and Austin, 1995), we compared Florida and African plants. We began by studying reproductive biology of the genus to compare *Dichondra carolinensis,* which has not been studied, with *D. micrantha,* which has (Forde, 1978). During this study we encountered not only *D. carolinensis* growing wild in southern Florida, but to our surprise, also *D. micrantha.* Further study of herbarium materials and historical documents indicates that the exotic species *D. micrantha* has been in Florida for over 60 years. The complex history of the spread of this species around the world has been described elsewhere (Austin, 1998).

Dichondra, with ca 16 species, was originally confined to the Americas, Australia and New Zealand; now pantropical because of purposeful and accidental human transport. The genus belongs to the tribe Dichondreae, which also includes *Falkia* L.f. (three species, all in Africa and one in the Arabian peninsula) and monotypic Ethiopian *Nephrophyllum* A. Richard (Sebsebe and Austin, 1995). This tribal distribution is the same as for organisms thought to be Gondwanan in origin and is but one example of such a pattern among convolvulaceous genera (Austin, unpubl. data).

There are subtle differences between several of the *Dichondra* taxa that have led different biologists to handle them in three ways: as all one variable species (e.g., *D. repens*), as varieties (e.g., *D. repens* var. *carolinensis*), or as distinct species. Not only are the various morphotypes recognizable, but they have distinctive ranges, and appear from floral morphology to be autogamous as experimental data have shown *D. micrantha* to be (Forde, 1978; Austin and Young, 1995). Thus, we accept Tharp and Johnston's (1961) view that they represent distinct species.

Dichondra J. R. & G. Forster, Char. Gen. Pl. 39, 40. t. 20. 1776. Type species: *D. repens* J. R. & G. Forster; type locality New Zealand.

Herbs with slender glabrous or pubescent mostly repent stems. Leaves cordate-orbicular to reniform, small, entire, with long petioles. Flowers inconspicuous, axillary, solitary (to paired) on long to short peduncles, usually less than 1 cm. wide, greenish- yellow to white; sepals subequal, barely united basally, often spathulate; corollas broadly campanulate to subrotate when living, appearing funnelform at times when dried, deeply 5-lobed, the lobes induplicate; ovary bilobate to emarginate, the lobes distinct or usually basally united, 2-locular, the styles 2, attached between the lobes and appearing almost gynobasic, filiform, the stigmas capitate. Fruits capsular or utriculate, 2-lobed to almost entire, membranaceous, usually 2-seeded, irregularly bivalvate or indehiscent; seeds obovoid, smooth, the cotyledons linear, 2-plicate.

Common names for the genus include: alfombra (Cuba), Carolina dichondra, dichondra, false pennywort, lawn-leaf, Mercury Bay weed (New Zealand), oreja de ratón (Mexico), pony-foot (with variants in Portuguese and Mandarin), sheep-grass (Bahamas), violeta japonesa (Cuba). These names are but a few of those in use (cf. Austin, 1998), and most are applied indiscriminately to several species.

KEY TO SPECIES

1. Flowers with petals and sepals ± the same length. Fruit on pedicels recurved just below the calyces; sepals about as long as fruit or shorter .... *D. micrantha*
1. Flowers with petals shorter than sepals. Fruits on nearly straight pedicels; sepals longer than the fruit .... *D. carolinensis*

1. *Dichondra carolinensis* Michaux, Flora Boreali-Americana 1:136. 1803. Type: U.S.A. South Carolina. "in Carolina, circa Charlstown [Charleston], &c." No specimen known. Fig. 1.

Anonymos repens Walter, Fl. Carol. 110. 1788. According to the international Code of Nomenclature (Greuter et al., 1994), all names placed in the genus "*Anonymos*" are invalidly published and are thus *nomina nuda.*

Demidofia repens [Walter] J. F. Gmelin, Syst. 1:458. 1791. Gmelin validated the Walter name by making this combination, but placed the epithet in a genus now considered a synonym of *Dichondra.*

Dichondra repens J. R. & G. Forster var. *carolinensis* (Michaux) Choisy in DC., Prodr. 9:451. 1845.

Dichondra evolvulacea (L.f.) Britton var. *carolinensis* (Michaux) Poiret ex O. Kuntze, Rev. Gen. 3(2):216. 1898.

Spreading, mat-forming herbs. Stems mostly 2–50 cm long, sparsely pubescent, the trichomes appressed or erect and medifixed, the internodes (0.5–)1–2(–4) cm long. Petiole 1–5(–10.5) cm long, sparsely pubescent;

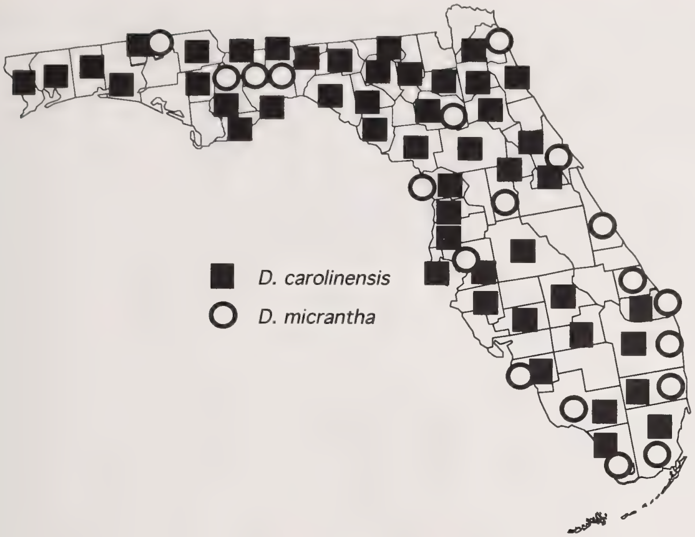


FIG. 1. Distribution of *Dichondra* in Florida.

leave blade suborbicular-reniform, somewhat cupped, thin, (6–)10–20(25) mm long, (9–)12–22(–30) mm wide, the base broadly cordate with a relatively shallow sinus, the apex rounded to shallowly emarginate, the veins on upper surface not conspicuous or depressed, upper leaf surface often remotely appressed pubescent, trichomes of lower leaf surface denser, appressed. Peduncle at flowering shorter or more often as long as or longer than petioles, (4–)8–20(–42) mm long, the flowers rarely below leaves, usually at level of leaves, or above. Flower 3–6 mm in diameter; calyx campanulate, the sepals 1.5–3 mm long, spathulate, obtuse apically, densely spreading pubescent without and ciliate on margins; corolla creamy-white, shorter than the calyx, 1.5–3 mm long, lobes oblong to slightly ovoid, the apex mostly obtuse, glabrous; anthers white, 0.3 mm long; styles 1–1.3 mm long, the stigmas at the same level as anthers; calyx lobes at fruiting accrescent to 3.5–5 mm long; peduncle at fruiting straight or barely nodding. Fruit contained within the longer calyx, 2–3 mm long, 1.6–2 mm thick, containing (1–)2 seeds. Seeds obovoid to pyriform, 1.8–2.7 mm long, tan to brown, smooth, dull.

Illustrations: While several publications have drawings of what is supposedly *D. carolinensis,* none has been found since Britton and Brown (1898, as *D. evolvulacea*) and Small (1933) that clearly illustrates that species (cf. Fig. 2). Most might be called 'generic' *Dichondra* (e.g., Radford et al., 1968, p. 862).

Distribution: Originally an endemic to southeastern United States (Virginia, North Carolina, South Carolina, Georgia, Florida, Mississippi, Alabama, Arkansas, Louisiana, Oklahoma, Texas) and Bermuda; there are spo-

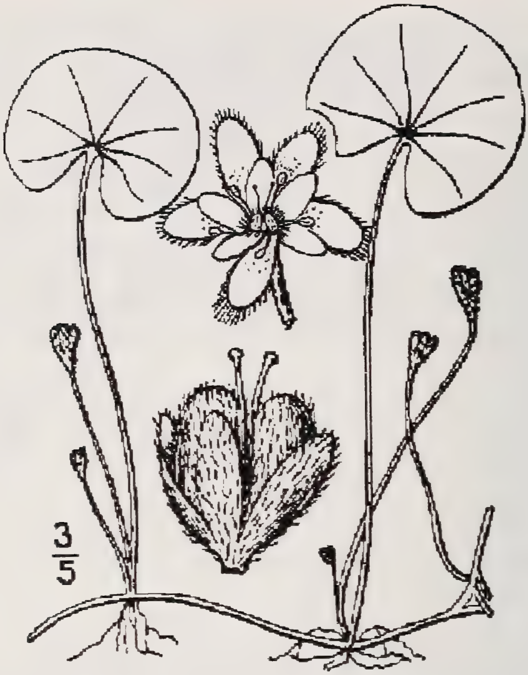


FIG. 2. *Dichondra carolinensis*. Drawing modified from Britton and Brown (1898).

radic records of the species in other states (e.g., Missouri, Howell Co. 29 Apr. 1991. *Summers 4210* MO; California, Solano Co. 2 Apr. 1943. *Schallert 42* MO). Found in pinelands, occasionally in hammocks. The species is less tolerant of full sun than *D. micrantha* and rarely grows where there is not some shade. Although found in lawns, the plants are usually restricted to the vicinity of buildings or under trees, particularly pines.

Phylogenetic analysis (cf. Austin, 1998) places *D. carolinensis* with *D. sericea* (Mexico and the Caribbean south to Argentina).

Selected specimens from Florida. ALACHUA. 2 Jul 1932. *L. A. Arnold* s.n. (FLAS). CALHOUN. 20 Mar 1949. *S. C. Houd 1613* (FLAS). CLAY. 15 Jul 1947. *West & Arnold* s.n. (FLAS); 30 Mar 1895. *A. L. Quanitance* s.n. (FLAS). DADE. no date. *Moldenke 5733* (NY). DUVAL. 8 Mar 1893. *A.H. Curtiss 4384* (MO); *A. H. Curtiss 2182* (FLAS, MO). ESCAMBIA. no date. *Tracy 7581* (MO, NY). FRANKLIN. 1868. *B. F. Sauman* s.n. (MO). GADSDEN. 10 Apr 1965. *W. H. Lewis 6553* (MO). HAMILTON. 11 Apr 1940. *West & Arnold* s.n. (FLAS). HOLMES. no date. *Godfrey 54422* (NY); JEFFERSON. *Lighthipe* Feb 1890 (NY). LAFAYETTE. 20 May 1941. *West & Arnold* s.n. (FLAS). LAKE. 3-30-1895. *A. L. Quaintance* s.n. (MO). LEE. 24 Feb 1969. *W. C. Brumbach 6622* (FLAS). LEON. Mar 1843. *Rugel* s.n. (MO, NY). LIBERTY. May 1898. *Chapman* s.n. (MO). MADISON. Jun-Jul 1898. *A. S. Hitchcock* s.n. (MO). MANATEE. 1 Apr 1942. *B. G. Arnold* s.n. (FLAS). MARION. 2 May 1941. *L. Baltzell 2953* (FLAS). PASCO. 13 Jan 1974. *L. Baltzell 5713* (FLAS). ST. JOHNS. 17 May 1996. *D. F. Austin* s.n. (FAU). SUMTER. 13 Mar 1975. *L. Baltzell 7112* (FLAS). SUWANEE. 23 Mar 1991. *B. & D. Herring 189* (FLAS). TAYLOR. 15 Mar 1939. *Exploration Party* s.n. (FLAS). UNION. 22 May 1942. *West & Arnold* s.n. (FLAS). VOLUSIA. 23 Apr 1971. *L. Baltzell 2874* (FLAS).

2. *Dichondra micrantha* Urban, Plantae cubenses Ekman II. Symbolae Antillanae 9:243. 1924. Type: Cuba, Oriente Province. Taco Bay, near Baracoa, *Ekman 3851a* (S, US!).

Spreading, mat-forming herb. Stems mostly 0.2–50 cm long, glabrous or pubescent, the trichomes appressed and medifixed, the internodes (0.5–)1–2(–3) cm long. Petiole 2–3.5(–6) cm long, densely to remotely pubescent; leaf blades reniform to broadly ovate-reniform, slightly cupped, thin, (3–)8–30 mm long, (3–)8–30 mm wide, the basal sinus broad, the apex shallowly emarginate to obtuse, the veins on upper leaf surface not conspicuous or depressed, the upper leaf surface usually glabrous, or sparsely hairy, patent, the veins on lower leaf surface prominent, the lower leaf surface remotely appressed pubescent. Peduncle at flowering much shorter than petioles, (3–)5–15 mm long, flowers hidden beneath leaves. Flower 3–4 mm diameter; calyx campanulate, the sepals 1.5–2 mm long, oblong to obovate, obtuse to subacute at apex, densely spreading and appressed pubescent without and ciliate on margins; corolla greenish to white, equal the calyx in length, 1.5–2 mm (at anthesis, up to 3 mm in old flowers), lobes lanceolate to oblong, subacute at apex to acute at apex, glabrous; anthers violet (or white in some plants), 0.3–0.4 mm long; styles 1.2 mm long, the stigmas about the same level as anthers; calyx at fruiting accrescent to 2.5–3 mm long; peduncle at fruiting recurved at apex. Fruit longer than calyx, 2–2.5 mm long, ca. 2 mm thick, containing (1)2(–3) seeds. Seeds subspherical to obovoid, or flattened on one side (if paired in one locule), 1.5–2 mm long, dark brown to black, smooth, dull.

Illustrations: Ooststroom (1953, Fig. 3, p. 395, as *D. repens*); Verdcourt (1963, Fig. 2, p. 13, as *D. repens*); Chang (1978:355, pl. 1036); Forde (1978: 284, 285, figs. 1–2); Correll and Correll (1982:1167, fig. 506, as *D. carolinensis*); Heine (1984, Pl. 2:1–11, p. 15, as *D. repens*).

Distribution: Found in North America (California, Arizona, New Mexico, Texas, Florida, Mexico, Cuba, Bahamas, a single specimen from Haiti (*Eckman 5406* NY), Europe, Africa, Asia, Australia and New Zealand. These may be common sunny lawn plants, especially where the grass has declined for some reason. Bare patches one year will be covered with these creeping herbs the next, and then grass the following. The populations are dynamic and rarely remain in a single spot more than one season.

Selected specimens from Florida. ALACHUA. 2 Mar 1986. *C. Easley 59* (FLAS). BREVARD. 16 Mar 1984. *S. R. Hill 13495* (MO). BROWARD. 26 Feb 1934. *L. Arnold* s.n. (FLAS). CITRUS. 3 Apr 1972. *L. Baltzell 3826* (FLAS). DADE. 15 Jan.-29 Feb 1992. *R. A. & E. S. Howard 20817* (FLAS).

DUVAL. 12 Feb 1990. *C. Easley 839* (FLAS). GADSDEN. 14 Mar 1937. *Exploration Party* (FLAS). HOLMES. 5 Mar 1956. *R. K. Godfrey 54422* (FLAS). PALM BEACH. *D. F. Austin* s.n. (FAU). ST. LUCIE. 17 May 1996. *D. F. Austin* s.n. (FAU). VOLUSIA. 17 May 1996. *D. F. Austin* s.n. (FAU).

Dichondra micrantha tends to be a more slender, delicate species than *D. carolinensis.* This tendency is doubtless involved with the tolerance *D. micrantha* has for open, sunny sites, while *D. carolinensis* seems to be restricted to more shaded sites. Where *D. micrantha* grows in partly shaded sites, such as near buildings, it gets as large as *D. carolinensis.*

Jill Young found this species and the native *D. carolinensis* growing on the Florida Atlantic University campus in Boca Raton in 1995. The herb has since been found widespread as a weed in lawns throughout the state. The first herbarium record in the state seems to be a collection made from lawns in Ft. Lauderdale (Broward Co., 26 Feb 1934. *Arnold s.n.* FLAS). Although no current vendors have been found that sell *Dichondra* within Florida, the species was touted as a lawn-grass substitute in the 1950s and 1960s when it was popularized in the Miami Herald (Anonymous 1953, 1960a, 1960b, 1961, 1962). Moreover, we have found three companies that still distribute *Dichondra* worldwide from the United States (cf. Austin, 1998). Even though the plants are not extremely popular, one California company averages selling 5,000–10,000 pounds of the 2 × 1 mm seeds per year.

Various people have speculated on where this species may be native; Lawalrée (1970) thought China, Manitz (1978) said Cuba, Webb and co-workers (1988) wrote ". . . an introduced American element . . . ," and Hatch and co-workers (1990) concluded it was Texas. Indeed, the area of nativity is unknown because the species has been spread and cultivated since the 1700s (Swartz 1797; Austin, 1998).

Johnston (1963) mapped the distribution in Texas and that was not significantly changed in the more recent study (Hatch et al. 1990). *Dichondra micrantha* mostly grows in the South Texas Plains, but some colonies are known from the gulf prairies and marshes and Edwards Plateau which it shares with *Dichondra carolinensis.* Even within the areas of shared habitat, the species are physically, and to some extent phenologically separated. There is a tendency in Florida for *D. micrantha* to reach peak flowering in March, while *D. carolinensis* peaks in April.

Phylogenetic analysis (cf. Austin, 1998) indicates that *D. micrantha* is related to *D. recurvata* (endemic to Texas) and *D. donelliana* (endemic to California); *D. micrantha* is sister to *D. recurvata.* Due to the cladistic placement with two endemic species, and its isolated range within different vegetational areas of Texas, it may be of North American origin.

ACKNOWLEDGMENTS—We thank the late Julia Morton (University of Miami) for providing critical historical references. Florida distribution is based on specimens deposited at F, FAU, FSU, FTG, MO, NY, UNC, USF and US.

LITERATURE CITED

ANONYMOUS. 1953. This stuff may save *Dichondra*. Miami Herald 10–11–1953.

———. 1960a. One's a penny weed, other's a dollar. Miami Herald 12–25–1960.

———. 1960b. Planters of *Dichondra*, beware. Miami Herald 7–17–1960.

———. 1961. Remember, *Dichondra* has its faults, too. Miami Herald 8–6–1961.

———. 1962. *Dichondra* needs care. Miami Herald. 8–18–1962.

AUSTIN, D. F. 1998. The indiscriminate vector: Human distribution of *Dichondra micrantha* (Convolvulaceae). Econ. Bot. 52(1):88–106.

——— AND J. YOUNG. 1995. Reproductive biology of *Dichondra* (Convolvulaceae). Paper presented at the 8th Annual Meeting of the South Florida Plant Biologists, Florida International University, Miami, FL.

BRITTON, N. L. AND A. BROWN. 1898. An Illustrated Flora of the Northern United States, Canada anda the British Possessions. New York, Charles Scribner's Sons.

CHANG, C.-E. 1978. Convolvulaceae Pp. 347–389. In: Flora of Taiwan, Vol. 4. Taipei, Taiwan, Epoch Publishing Co., Ltd.

CLEWELL, A. F. 1982. Guide to the Vascular Plants of the Florida Panhandle. University Presses of Florida/Florida State University Press. Tallahassee, FL.

CORRELL, D. S. AND H. B. CORRELL. 1982. Flora of the Bahama Archipelago. J. Cramer, Vaduz, Germany.

DEMISSEW, S. AND D. F. AUSTIN. 1995. The genus *Nephrophyllum* (Convolvulaceae, tribe Dichondreae) in Ethiopia. Kew Bulletin 50(1):103–108.

FORDE, 1978. The cultivated dichondra. New Zealand Journal of Botany 16:283–285.

GODFREY, R. K. and J. W. WOOTEN. 1981. Aquatic and Wetlands Plants of Southeastern United States, Dicotyledons. University Georgia Press, Athens, GA.

GREUTER, W., F. R. BARRIE, H. M. BURDET, W. G. CHALONER, V. DEMOULIN, D. L. HAWKSWORTH, P. M. JØRGENSEN, D. H. NICOLSON, P. C. SILVA, AND O. TREHANE. 1994. International Code of Botanical Nomenclature (Tokyo Code). Koeltz Scientific Books, Königstein, Germany.

HATCH, S. L., K. N. GANDHI, AND L. E. BROWN. 1990. Checklist of the Vascular Plants of Texas. publication MP-1655 of the Texas Agricultural Experiment Station, Texas A&M University, College Station, TX.

HEINE, H. 1984. Convolvulaceae. Flore de la Nouvelle-Calédonie et dépendances. Muséum National d'Histoire Naturelle, Paris.

JOHNSTON, M. C. 1963. The geography of five Texas species of *Dichondra* (Convolvulaceae). Wrightia 1: 252–253.

LAWALRÉE, A. 1970. Definition, aire et mode de dessemination de *Dichondra micrantha* Urban (Convolvulaceae). Acta Bot. Neerland. 19(5):717–721.

LONG, R. W. AND O. LAKELA. 1971. A Flora of Tropical Florida. University Miami Press, Miami, FL.

MANITZ, H. 1978. Zur Verbreitung von *Dichondra micrantha* Urb. (Convolvulaceae) in Cuba. Wissenschaftliche Zeitschrift der Friedrich-Schiller-Universität Jena/Thüringen Mathematisch-Naturwissenschaftliche Reihe 27:27–33.

OOSTSTROOM, S. J. VAN. 1953. Convolvulaceae. Flora Malesiana ser. 1, 4(4):388–512. Noordhoof-Kolff n.v., Djakarta, Indonesia.

RADFORD, A. E., H. E. AHLES, AND C. R. BELL. 1968. Manual of the Vascular Flora of the Carolinas. University North Carolina Press, Chapel Hill, NC.

SEBSEBE, D. AND D. F. AUSTIN. 1995. The genus *Nephrophyllum* (Convolvulaceae, tribe Dichondreae) in Ethiopia. Kew Bull. 50(1):103–108.

SMALL, J. K. 1933. Manual of the Southeastern Flora. University North Carolina Press, Chapel Hill, NC.

SWARTZ, O. 1797. Flora Indiae Occidentalis. Londini, B. White et Filium, 1:555–556.

THARP, B. C. AND M. C. JOHNSTON. 1961. Recharacterization of *Dichondra* (Convolvulaceae) and a revision of the North American species. Brittonia 13(4): 346–360.

Verdcourt, B. 1963. Convolvulaceae. Flora of Tropical East Africa. Crown Agents for Oversea Governments and Administrations, London.

Webb, C. J., W. R. Sykes, and P. J. Garnock-Jones. 1988. Flora of New Zealand, Vol. IV. Naturalized pteridophytes, gymnosperms and dicotyledons. Botany Division, D.S.I.R., Christchurch, NZ.

Wunderlin, R. P. 1982. Guide to the Vascular Plants of Central Florida. University Presses of Florida/University South Florida Press, Tampa, FL.

Florida Scient. 61(3/4): 195–202. 1998
Accepted: March 19, 1998

Biological Sciences

RAPD ANALYSIS OF THE LAST POPULATION OF A LIKELY FLORIDA KEYS ENDEMIC CACTUS

D. R. GORDON AND T. L. KUBISIAK(1)

The Nature Conservancy, Department of Botany, P.O. Box 118526, University of Florida, Gainesville, Florida 32611 and (1)USDA Forest Service, Southern Research Station, Southern Institute of Forest Genetics, 23332 Highway 67, Saucier, Mississippi 39574

ABSTRACT: *The semaphore cactus in the Florida Keys has until recently been considered a disjunct location of the Jamaican* Opuntia spinosissima. *Loss of all but one population in the Keys coupled with recent suggestions that the species should be taxonomically separated from the Jamaican cactus and is, therefore, a Florida Keys endemic, makes this population of conservation concern. Random amplified polymorphic DNA (RAPD) analysis was conducted on the remaining 12 individual large stems in the wild to determine whether this small population contains multiple genotypes. Other accessions of the cactus, mainly from private collections and from the Caribbean were also included. Analysis of 42 RAPD markers reveals that all Florida accessions are closely related, with unique genotypes being separated by differences at only one to as many as five polymorphic markers (2.4–11.9% of markers). Within the wild population, seven genotypes could be uniquely identified. The Jamaican accession was separated from the Florida cacti by an average of 22 marker differences (52.3% of the markers). The difference of the Florida accessions from the Jamaican accession by a large number of markers suggests possible species-level differentiation, providing additional supportive evidence that the Keys population may be one of the rarest and most threatened plants in the continental United States.*

THE semaphore cactus, *Opuntia spinosissima* Miller (1768), is an erect tree cactus historically known from only three locations within the United States. These locations were all within Monroe County, Florida: on Big Pine Key, Key Largo, and Little Torch Key. The first two of these populations were noted by Small (1930), who found a record of the Big Pine Key population in 1919. The third population was not discovered until 1965 (The Nature Conservancy, 1990). Some authors have hypothesized that the Little Torch Key population was introduced from propagated stock (Avery, 1981), but no evidence documents this hypothesis.

The only remaining population in the Florida Keys is that on Little Torch Key, the two other populations having been extirpated as land development progressed (The Nature Conservancy, 1990). The Little Torch Key population was significantly threatened by collection in 1977, but has been protected from further such damage since 1988 by The Nature Conservancy. At that time, there were 13 large separately rooted stems, most surrounded by several smaller rooted stems. The smaller stems are likely to be vegetative, forming when pads drop from the larger "adult" plants and take root.

Most of the pads that drop are aborted fruit pads. Viable seeds were not recorded from the plants until 1996. Currently, it is not known whether any of the smaller stems are progeny derived from seed.

While the primary location for this rare cactus has been thought to be in the Blue Hills of south coastal Jamaica, recent work suggests that the populations in Jamaica and Florida are sufficiently morphologically and genetically different to be taxonomically separated. The Florida cacti have now been proposed as more appropriately identified as *Opuntia corallicola* Small (Austin et al., 1997). This assessment is supported by earlier work by Howard and Touw (1982), who listed *O. spinosissima* as endemic to Jamaica. However, the species has also been cited from Cayman Brac (Adams, 1972).

Three lines of evidence suggest that the taxonomic differentiation is appropriate, and that the species is a Florida Keys endemic. First, Austin and Binninger (1994) determined that the Florida cacti differ from the Jamaican ones in areole, corolla, ovary, pad, and spine characteristics, height, and habitat. Chromosome numbers could not be used for this analysis because while $2n = 66$ for the Florida accessions, the data are not available for the Jamaican population (Austin et al., 1997). Accession material for this work, and for all the work discussed below, was obtained from Fairchild Tropical Garden, which maintains a Center for Plant Conservation collection of this species.

Second, enzyme electrophoresis of 18 accessions from the Florida Keys and 29 from Jamaica (all from a single fruit) was conducted on 13 loci (Hamrick and Godt, 1996). The analysis showed no allozyme diversity among the Florida Keys individuals, which were homozygous at all loci except one, a fixed heterozygote. Four loci were polymorphic in the Jamaican plants, with the mean number of alleles per locus at 2.25. One locus was fixed for different alleles in the Florida and Jamaican plants, while the remainder overlapped. Nei's genetic identity between the two groups was 0.801 (Hamrick and Godt, 1996). The authors concluded that the groups are closely related but could be different species if the variation in the Jamaican accessions was artificially low because of their related source.

Third, Dougherty (1996) examined ribulose *bis*phosphate carboxylase-oxygenase (*rbc*L) genes of chloroplast DNA in the cacti. The nucleotide sequence variation demonstrated differentiation between the Florida and Jamaican plants sufficient to support the taxonomic differentiation. The author did not evaluate whether there were differences in sequence among the individuals in Florida (Dougherty, 1996).

In order to clarify whether the Little Torch Key semaphore cactus population is composed of one or multiple genetic individuals, we embarked on an additional examination of DNA using random amplified polymorphic DNAs (RAPDs). This information would aid in The Nature Conservancy's management of the remaining wild individuals on the preserve. Two introduction efforts have been undertaken with propagules from 11 of the individuals on the preserve. A collaborative experimental out-planting has been initiated in two areas disjunct from the wild population on the preserve using propagules from four of the parent plants. An additional series of out-plantings has been conducted by Fairchild Tropical Garden on Big Pine Key and Key Largo. In all cases, accession identity has been recorded. Genetic identities of these accessions may clarify any patterns in growth and survival that are detected.

MATERIALS AND METHODS—*Plant material*—Pads from 21 accessions at Fairchild Tropical Garden were placed in separate paper bags, frozen, placed on dry ice, and shipped overnight to the USDA Forest Service, Southern Institute of Forest Genetics, in Saucier, Mississippi. The accessions included: 12 of the large cacti from the Little Torch Key population (LTK); three cacti from private collections on Little Torch Key (PLTK); one cactus from a private collection from an unspecified location in the lower Keys (LK); one cactus from lower Matecumbe Key (MK); two cacti that had been planted at Castello Hammock Park (PCHP) in Miami-Dade County, Florida; one cactus from a private collection derived from Cayman Brac (CAY); and one cactus from Jamaica (JAM).

DNA extraction—Total nucleic acids were isolated from approximately two grams of cactus pad tissue using a modification of the CTAB-based procedure outlined in Wagner and co-workers (1987). The RNA component of these individual extracts was removed by incubation in the presence of RNase A as described in Ausubel and co-workers (1987). Oligonucleotide 10-mer primers were obtained from Operon Technologies (Alameda, Calif., USA).

RAPD amplification—DNA amplification was based on the protocol reported by Williams and co-workers (1990). The reaction consisted of the following in 24 μl total volume: 6.25 ng of template DNA, 1 μl of primer DNA (5 μM stock), 3.6 μl of dNTPs (1 mM stock), 2.4 μl 10× *Taq* DNA polymerase reaction buffer (500 mM KCl, 100 mM Tris-HCl, 1.0% Triton® X-100, 15 mM $MgCl_2$), and 0.8 U *Taq* DNA polymerase. Reactions were loaded in flexible microtitre plates and overlaid with 25 μl of mineral oil. Microtitre plates were placed in preheated (85°C) programmable temperature cyclers (MJ Research PTC-100) and covered with mylar film. The DNA samples were amplified using the following thermal profile: 5 s at 95°C; 1 min 55 s at 92°C; followed by 45 cycles of 5 s at 95°C, 55 s at 92°C, 1 min at 35°C, and 2 min at 72°C; followed by 7 min at 72°C. The reactions ended with an indefinite hold at 4°C.

Electrophoresis—The completed reactions were electrophoresed in 2% agarose gels and TAE buffer (40 mM Tris base, 20 mM sodium acetate, 2.0 mM EDTA, glacial acetic acid to pH 7.2) for approximately 3.5 h at 3 V/cm (150 V). A total of 3.0 μl of loading buffer (10× TAE, 50% glycerol, 0.25% bromophenol blue) was added to each reaction prior to electrophoresis. After electrophoresis, the gels were stained with ethidium bromide (0.4 μg/ml) for 45 min, washed in dH_2O for 1.0 h, and photographed under UV light using a Polaroid MP-4 camera and Polaroid 667 instant film.

Primer screening and marker scoring—To identify informative RAPD fragments, a total of 20 oligonucleotide primers (Operon Technologies Inc. primer sets A and B) were screened against a panel of DNAs extracted from the 21 different cacti. Those fragments found to be polymorphic among the 21 samples were scored as potentially informative. Markers were subjectively chosen based on the intensity of amplification (only intensely amplified bands were scored) and absence of co-migrating DNAs (Fig. 1). Those cases in which a reaction completely failed or the presence or absence of bands was unclear, were recorded as missing data. RAPD fragments were identified by the manufacturer primer code corresponding to the primer responsible for their amplification, followed by a four digit number indicating the approximate fragment size in base pairs.

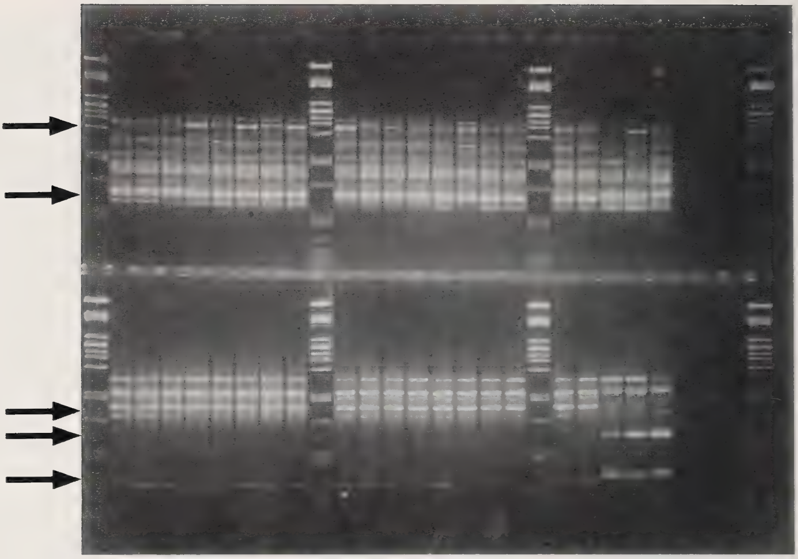


FIG. 1. Ethidium bromide-stained 2.0% agarose gel showing polymorphic markers among the 21 cacti accessions amplified by Operon Technologies primer A01(upper panel) and A07 (lower panel). RAPDs are identified by arrows. Lanes 1, 10, 19, and 28 are lambda-*Pst*I molecular weight size ladders. Lanes 2–9 contain samples LTK 90-192 through 90-199; lanes 11–18 contain samples LTK 90-200 through 90-203, PLTK 86-103, 93-416, and LTU1, and LK 92-372; and lanes 20–24 contain MK 92-534, PCHP 89-620, PCHP CHU2, CAY 96-131, and JAM 90-253.

Cluster analysis—Cacti samples were placed into groups or clusters using the unweighted pair-group mean method (UPGMA) available under the CLUSTER procedure in the statistical analysis software SAS (SAS Institute Inc., Cary, NC). A distance or dissimilarity matrix was constructed based on the RAPD fragment data. Cacti samples were scored for the presence or absence of a band at each of the RAPD fragments. The distance matrix was constructed by tallying the total number of marker differences found between pair-wise comparisons. For the 21 samples, a total of 231 pair-wise comparisons were made.

RESULTS—A total of 42 RAPD markers were identified in the cactus samples. The distance matrix constructed for cluster analysis is shown in Table 1. UPGMA analysis suggested two primary groups of individuals (Fig. 2). One primary group included all of the Florida cacti except for one of the two cacti planted at Castello Hammock Park. The other primary group included the other Castello Hammock Park cactus, the Cayman Brac accession, and the Jamaican accession.

Within the larger grouping, additional differentiation among accessions was evident. This separation was based on differences at only a few (one to five) RAPD markers. Of the 12 large cacti from the Little Torch Key population, seven appear to be unique genotypes (Fig. 2). The three cacti from private collections on Little Torch Key (PLTK LTU1, 86-103 and 93-416), are all indistinguishable based on these data. These cacti were also

TABLE 1. Dissimilarity matrix for the 21 cacti accessions based on the number of marker differences found between pair-wise comparisons of samples at 42 RAPD markers.

Cactus accession	Symmetric dissimilarity matrix																				
PLTK 86-103	0																				
PCHP 89-620	2	0																			
LTK 90-192	0	2	0																		
LTK 90-193	0	2	0	0																	
LTK 90-194	2	4	1	2	0																
LTK 90-195	4	4	3	4	4	0															
LTK 90-196	1	3	1	1	1	5	0														
LTK 90-197	3	1	3	3	5	4	4	0													
LTK 90-198	2	0	2	2	4	4	3	1	0												
LTK 90-199	1	3	1	1	3	3	2	2	3	0											
LTK 90-200	3	1	3	3	5	3	4	0	1	2	0										
LTK 90-201	1	3	1	1	1	5	0	3	3	2	4	0									
LTK 90-202	1	3	1	1	1	5	0	4	3	2	4	0	0								
LTK 90-203	2	4	1	2	0	4	1	5	4	3	5	1	1	0							
JAM 90-253	24	26	23	21	26	25	22	27	26	25	27	25	23	26	0						
LK 92-372	1	3	1	1	3	5	2	4	3	2	4	2	2	3	25	0					
MK 92-534	0	2	0	0	1	4	0	3	2	1	3	0	0	1	23	1	0				
PLTK 93-416	0	2	0	0	2	4	1	3	2	1	3	1	1	2	24	1	0	0			
CAY 96-131	17	17	17	14	19	14	17	18	17	18	18	18	18	19	24	16	17	17	0		
PCHP CHU2	23	25	23	20	24	20	23	26	25	24	26	24	24	24	12	24	22	23	18	0	
PLTK LTU1	0	2	0	0	1	3	1	3	2	1	3	1	1	1	21	1	0	0	16	22	0

indistinguishable from two of the 12 cacti in the wild Little Torch Key population (LTK 90-192 and 90-193). It is not possible to say exactly which wild cacti may have provided material for the private collections, however, it is possible they are clones of one or both of these cacti. One of the cacti planted at Castello Hammock Park in Dade County, Florida (PCHP 89-620) could not be distinguished from one of the 12 cacti in the wild Little Torch Key population (LTK 90-198), suggesting that it may have originally been collected from Little Torch Key.

Within the smaller group, the Jamaican accession (JAM 90-253) and the other cactus planted at Castello Hammock Park (PCHP CHU2) differed at only 12 markers. Both accessions differed from the Florida accessions by an average of 24 markers, suggesting that PCHP CHU2 was probably not collected from Little Torch Key. The Cayman Brac accession (CAY 96-131) differed from the Florida accessions by an average of 16 markers, the Castello Hammock Park cactus (PCHP CHU2) by 18 markers, but differed from the Jamaican accession by 24 markers. Currently, we do not know any additional information about the Cayman Brac accession, but it clusters more closely with the Florida accessions than with the Jamaican accession.

The large number of marker differences observed among the Florida accessions and the Jamaican accession provides further evidence that the Florida population may not be *O. spinosissima* as originally classified. The differences reported here are suggestive of possible species level differences,

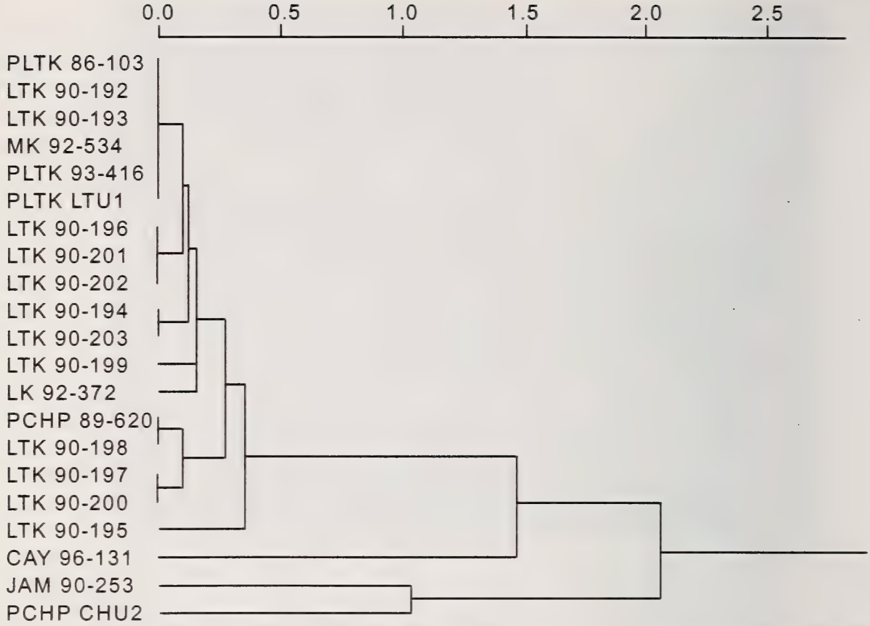


FIG. 2. Unweighted pair group mean cluster dendrogram constructed from a distance matrix based on data from 42 random amplified polymorphic DNA markers collected on 21 cacti accessions. Those accessions beginning with the prefix LTK were collected from Little Torch Key, those beginning with PLTK were from private collections on Little Torch Key, and those beginning with PCHP had been planted at Castello Hammock Park in Dade County, Florida. The accession beginning with PLK was from a private collection from an unspecified location in the Lower Keys, that beginning with MK was from lower Matecumbe Key, that beginning with CAY was from a private collection derived from Cayman Brac, and that beginning with JAM was collected from Jamaica.

however, we cannot overlook the fact that these differences may simply be due to sampling as only a single Jamaican accession was available.

The clustering pattern within the larger Florida-derived group is consistent with differences identified in Dougherty's (1996) *rbc*L DNA sequence work. The DNA sequence data suggested that Florida accessions LTK 90-194 and 90-199 are different, and that LTK 90-200 is different from 90-202 and 90-203. The RAPD marker data confirm the differences among these cacti, as well as providing additional evidence for further differentiation among the Little Torch Key accessions.

Comparison of the RAPD clustering pattern of individuals from the Little Torch Key population with their geographic location on the preserve reveals that geographic proximity does not always correlate with genetic relatedness. Some of the accessions within a meter to a few meters of each other (e.g., LTK 90-195 and 90-196 or LTK 90-200 and 90-201) are less related than are accessions approximately 50 m apart (e.g., LTK 90-192 and

90-201). Thus, assumptions about relatedness that might have been made based on location can now be avoided.

DISCUSSION—These data provide additional support that the Little Torch Key opuntia, if really a Florida Keys endemic species, may be among the most endangered plant species. The data also increase the likelihood that the remaining population is not the result of either an anthropogenic introduction or rafting material carried by storm events from the Caribbean, both of which would probably have been of one individual. Greater proximity and species exchange among the Caribbean islands and with the Florida Keys in earlier geologic times may have allowed spread and then isolation of the species (Dilcher, 1997). Loss of genetic variability through founder effects or inbreeding is possible. Regardless of origin, protection of the imperiled wild population and recovery of the species is critical.

Fortunately, several steps toward recovery are already underway. Viable seeds are now being produced in both the wild and *ex situ* populations. Current research is directed toward identifying the breeding system and should identify techniques for increasing successful pollination (Negron-Ortiz, 1997). Several introduced or re-introduced populations have now been established by Fairchild Tropical Garden and The Nature Conservancy. Differences among accessions in quantitative traits may now be evaluated from these out-plantings. On the preserve, four of the genotypes identified in this study were planted. Phenotypic differentiation in different environments may provide additional clarification of the differences among individuals.

The greatest threats to recovery of this species appear to be collection and predation by the introduced cactus moth, *Cactoblastis cactorum*. However, for a species not yet listed, much progress toward recovery has already been made.

ACKNOWLEDGMENTS—We are grateful to Dena Garvue of Fairchild Tropical Garden for maintaining the collection of *O. spinosissima* and making it available for these analyses, to Laura Flynn for providing site information, to Rob Doudrick for facilitating sample analysis, and to Glen Johnson and Kristel Davis for technical expertise in DNA extraction and the polymerase chain reaction, respectively. We also appreciate the ability to cite unpublished reports by D. Austin, D. Binninger, C. Dougherty, J. Hamrick, and M.J. Godt. P. Stiling and two reviewers provided helpful comments on this manuscript.

LITERATURE CITED

ADAMS, C.D. 1972. Flowering plants of Jamaica. Univ. of the West Indies, Mona, Jamaica.

AUSTIN, D. F. AND D. M. BINNINGER. 1994. The endangered Florida semaphore cactus. Final report to the U.S. Fish and Wildlife Service, Contract No. 41910–2–0174. Jacksonville, FL.

———, D. M. BINNINGER, AND D. J. PINKAVA. 1997. Phylogenetic analysis of the endangered Florida semaphore cactus (*Opuntia corallicola*). Sida. Submitted.

AUSUBEL, F. M., R. BRENT, R. E. KINGSTON, D. D. MOORE, J. G. SEIDMAN, J. A. SMITH, AND K. STRUHL. 1987. Current protocols in molecular biology. John Wiley & Sons, New York, NY.

Avery, G. 1981. A history of the Cactaceae of the southeastern United States. Cactus Succul. J. 53:177–182.

Dilcher, D. L. 1997. Florida Museum of Natural History, Univ. of Florida, Gainesville, FL, Pers. Commun.

Dougherty, C. J. 1996. Novel DNA sequences of the endangered Florida semaphore cactus. M.S. Thesis, Florida Atlantic University. Boca Raton, FL.

Hamrick, J. L. and M. J. W. Godt. 1996. Genetic diversity in *Opuntia spinosissima,* a rare and endangered Florida Keys cactus. Final report to The Nature Conservancy. Key West, FL.

Howard, R. A. and M. Touw. 1982. *Opuntia* species in the Lesser Antilles. Cactus Succul. J. 54:107–179.

Negron-Ortiz, V. 1997. Botany Dept., Miami Univ., Oxford, OH, Pers. Commun.

Small, J. K. 1930. *Consolea corallicola,* Florida semaphore cactus. Addisonia 15:25–26.

The Nature Conservancy. 1990. Element stewardship abstract on *Opuntia spinosissima.* The Nature Conservancy, Arlington, VA.

Wagner, D.B., G. R. Furnier, M. A. Saghai- Maroof, S. M. Williams, B. P. Dancik, and R. W. Allard. 1987. Chloroplast DNA polymorphisms in lodgepole and jack pines and their hybrids. Proc. Natl. Acad. Sci. USA 84:2097–2100.

Williams, J. G. K., A. R. Kubelik, K. J. Livak, J. A. Rafalski, and S. V. Tingey. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. Nucleic Acids Res. 18:6531–6535.

Florida Scient. 61(3/4): 203–210. 1998
Accepted: March 31, 1998

FLORIDA ACADEMY OF SCIENCES MEDALISTS

1963	Dr. Archie Carr	University of Florida	Biology
1964	Dr. Werner A. Baum	University of Miami	Meterology
1965	Dr. Alex G. Smith	University of Florida	Astronomy
1966	Dr. Karl Dittmer	Florida State University	Chemistry
1967	Dr. Alfred H. Lawton	University of South Florida	Medicine
1968	Dr. Sidney Fox	University of Miami	Biochemistry
1969	Dr. F. G. Walton Smith	University of Miami	Marine Science
1970	Dr. Pierce Brodkorb	University of Florida	Zoology
1971	Dr. Maurice A. Barton	Mound Park Foundation	Medicine-Teaching
1972	Dr. Lloyd M. Biedler	Florida State University	Physiology Biophysics
1973	Dr. Ruth S. Breen	Florida State University	Botany
1974	Dr. E. T. York, Jr.	University of Florida	Agriculture
1975	Dr. Alex E. S. Green	University of Florida	Physics
1976	Dr. Robert N. Ginsburg	University of Miami	Geology
1977	Dr. Michael Kasha	Florida State University	Molecular Biophysics
1978	Dr. John Edward Davies	University of Miami	Public Health
1979	Dr. Stanley S. Ballard	University of Florida	Optics
1980	Dr. Thomas D. Carr	University of Florida	Astronomy
1981	Dr. Harold J. Humm	University of South Florida	Marine Biology
1982	Dr. George B. Butler	University of Florida	Chemistry
1983	Dr. Karen Steidinger	Florida Dept. Natural Resources	Biology
1984	Dr. Yngve Ohrne	University of Florida	Chemistry
1985	Dr. William Sears	Florida Atlantic University	Anthropology
1986	Dr. E. Dwight Adams	University of Florida	Physics
1987	Dr. Larry Hench	University of Florida	Engineering
1988	Dr. Gene C. Ness	University of South Florida	Biochemistry
1989	Dr. Frank Bradshaw Wood	University of Florida	Astronomy
1990	Dr. Martin Uman	University of Florida	Electrical Eng'n
1991	Dr. Frank Millero	University of Miami	Oceanography
1992	Dr. Gregory Choppin	Florida State University	Chemistry
1993	Dr. D. O. Shah	University of Florida	Chemical Eng'n
1994	Mrs. Barbara B. Martin	University of South Florida	Chemistry
	Dr. Dean F. Martin	University of South Florida	Chemistry
1995	Dr. James N.Layne	Archbold Biological Station	Zoology
1996	Dr. Leslie Sue Lieberman	University of Florida	Anthropology
1997	Dr. George R. Newkome	University of South Florida	Chemistry
1997	Dr. George R. Newkome	University of South Florida	Chemistry
1998	Dr. Joseph J. Krzanowski	University of South Florida	Pharmacology

OMITTED ABSTRACTS

The following two abstracts were inadvertently omitted from the Program issue of the 62nd annual meeting, March 26–28, 1998. The papers were contributed to the Science Teaching Section. The omission, while regretted, was not the fault of the Editors nor the Co-Program Chairs.

Positive Student Attitude Shift Toward the Use of Animals in Research Following Teacher Workshops. E. M. GRANGER, Office of Science Teaching Activities, Florida State University, Tallahassee, 32306-1100.

We created a workshop for middle- and high-school science teachers that addressed, first, what basic research is and why it is done, and second, why responsible animal use is needed in basic as well as applied research. Over 1100 teachers participated, including teachers from all but 6 of Florida's 67 counties. A questionnaire was designed to measure the attitudes of secondary-school students toward the use of animals in research , validated, and then administered to students throughout Florida using a stratified- cluster sampling plan prior to any teacher workshops. Following two years of workshops, students of teacher participants were stratified and sampled as before. The data show statistically significant positive shifts in student attitudes about the use of animals in research following this educational intervention via teachers. The shift was greater for females than males and for middle-school students than for high-school students.

Saturday-at-the-Sea: What Students Learn in Experiential Science Education Programs. C.D. BOWLING AND D.E. GRANGER. Florida State University, Tallahassee, FL 32306-1100.

Saturday-at-the-Sea (SATS) is an experience-based, marine environmental education program for middle-school students offered by Florida State University. During a day of SATS, students consider how to test observations through the use of multiple hypotheses and explore the organisms that live in coastal habitats through field trips and in a wet laboratory equipped with microscopes and touch tanks. Participants in the SATS program not only experience a change in their understanding of the marine environment (as tested through pre- and post-SATS drawings) as a result of their participation in the program, but also experience a positive shift in their attitudes concerning scientists, their leisure interest in science, and their interest in science as a career (as tested through the use of the Test of Science Related Attitudes, Fraser 1981.)

FLORIDA SCIENTIST

QUARTERLY JOURNAL
OF THE
FLORIDA ACADEMY OF SCIENCES

VOLUME 61
Dean F. Martin
Editor
Barbara B. Martin
Co-Editor

1936

Published by the

Florida Academy of Sciences, Inc.
Indialantic, Florida
1998

The Florida Scientist continues the series formerly issued as the Quarterly Journal of the Florida Academy of Sciences. The Annual Program Issue is published independently of the journal and is issued as a separately paged Supplement.

Copyright © by the Florida Academy of Sciences, Inc. 1998

CONTENTS OF *FLORIDA SCIENTIST* VOLUME 61

Number One

Growth Response of Dioecious Hydrilla to Phosphorus and Bicarbonate Utilization .... Kerry K. Steward 1

Occurrence of the Manta Ray, *Manta birostris,* in the Indian River Lagoon, Florida .... Douglas H. Adams and Elena Amesbury 7

Management of the Florida Red Tide—Revisited .... Dean F. Martin and William H. Taft 10

Enhanced Solubility of Sodium Fluorosilicate Scale by Magnetic Treatment .... Chuhua Wang, Robert F. Benson, and Dean F. Martin 17

Analysis of Selenium: An Annotated Bibliography .... Eileen Pérez, Gregory S. Corbett, Christopher J. Coston, Maria T. Gallardo, James D. Hayes, and Dongxin Wang 26

Desmognathus auriculatus at Devil's Millhopper State Geological Site, Alachua County, Florida .... C. Kenneth Dodd, Jr. 38

Effects of Humic Acid on The Solubility Product Constants of Some Environmentally Significant Calcium Compounds .... Warren C. Fiskus and Thomas J. Manning 46

An Annotated Bibliography of Allelopathic Properties of Cattails, *Typha spp.* .... Maria T. Gallardo, Barbara B. Martin, and Dean F. Martin 52

Review .... Frederick B. Essig 59

Books Received 60

Number Two

Herpetofaunal Surveys of the Big Bend Wildlife Management Area, Taylor County, Florida .... Kevin M. Enge and Kristin N. Wood 61

Removal of Iron from Sodium Fluorosilicate Scale by Magnetic Treatment .... Chuhua Wang, Robert F. Benson, and Dean F. Martin 88

Florida and Global Warming .... Jay W. Palmer 96

Invasive Exotic Climbers in Florida: Biogeography, Ecology, and Problems .... Daniel F. Austin 106
Effects of Submergence on Embryonic Survival and Development Rate of the Florida Applesnail, *Pomacea paludosa:* Implications for Egg Predation and Marsh Management .... Richard L. Turner 118
Single Node Aquifer Analysis—A Water Budget Model .... R. P. Haviland 130
Book Review .... William H. Taft 139
Book Review .... Dean F. Martin 140

Number Three/Four

Herpetofaunal Survey of an Upland Hardwood Forest in Gadsen County, Florida .... Kevin M. Enge 141
Status and Conservation of Southeastern Myotis Maternity Colonies in Florida Caves .... Jeffrey A. Gore and Julie A. Hovis 160
Acknowledgment of Reviewers 170
Land Use and Land Cover Trends in Florida, 1936–1995 .... Randy S. Kautz 171
Age and Growth of a Newly Established White Bass Population in Florida .... Jeffrey J. Nordhaus, Brian R. Lubinski, Richard L. Cailteux, and Daniel A. Dobbins 188
Studies of the Florida Convolvulaceae—VI. *Dichondra* .... Daniel F. Austin, Sebsebe Demissew, and Jill Young 195
RAPD Analysis of the Last Population of a Likely Florida Keys Endemic Cactus .... D. R. Gordon and T. L. Kubisiak 203
Florida Medalists 211
Omitted Abstracts 212
Table of Contents, Volume 61 213

INSTRUCTION TO AUTHORS

Individuals who wish to publish in the *Florida Scientist* must be active members in the Florida Academy of Sciences.

Submit a typewritten original and two copies of the text, illustrations, and tables to the editors. All typewritten material–including the abstract, literature citations, footnotes, tables, and figure legends–shall be double-spaced. Use one side of 8½ × 11 inch (21½ cm × 28 cm) good quality bond paper for the original; the copy may be xeroxed. Margins should be at least 3 cm all around. Number the pages through the Literature Cited section. Avoid footnotes and do not use mimeo, slick, erasable, or ruled paper. Use metric units for all measurements. *Papers in excess of 10 pages by an author in a single volume will result in page charges ($57 per page) for the excess pages.*

Address follows the author's name.

Abstract–all manuscripts shall have a short, concise, single-paragraphed abstract. The abstract follows immediately the author's address.

Acknowledgments are given in the body of the text preceding immediately the Literature Cited section.

Literature Cited section follows the text. Double-space every line and follow the format in the current issue.

Manuscripts of 5 or less, double-spaced typewritten pages should conform to the short article protocol. See recent issue for proper format of both long and short articles.

Tables shall be typed on separate sheets of paper, double-spaced throughout. Each table shall contain a short heading. Do not use vertical rulings. Maximum character width, including spaces, of tables is 98.0. This includes a minimum space of 5 characters between columns.

Illustrations–All drawings shall be done in good quality India ink, on good board or drafting paper. Letter by using a lettering guide or equivalent. Typewritten letters on illustrations are unacceptable. Drawings and photographs should be large enough to allow ⅓ to ½ reduction in size. Photographs shall be glossy prints of good contrast. Whenever possible, mount photographs in lots size.

The author's name and figure number should be penciled lightly on the back of each figure. Figure legends must be listed on a separate page and not on the drawing or photograph. The legend must be double spaced. Illustrations are charged to authors at $16.00 for halftones and $11.00 for line art.

We ask authors to prepare accepted manuscripts in personal computer formats. **Please do not submit a manuscript on disk.** Once reviewers have recommended a manuscript be accepted, you will be given directions for submitting the **final manuscript on disk.**

Proof must be returned promptly. Notification of address change and proofreading are the author's responsibility. Alterations after the type has been set will be charged to the author.

Reprints may be ordered through the Business Manager from the printer on forms provided at the time that proofs are sent to authors for checking.

FLORIDA ACADEMY OF SCIENCES

Institutional Members for 1998

Brevard Community College, Palm Bay
The British Library, Boston Spa, Weatherby, UK
The British Library, RAS Washington DC Professional Campus
Cleveland Public Library, Cleveland, OH
Edison Community College
Florida International University
Harbor Branch Oceanographic Institution, Inc.
Long Island University
Museums Library, University of Michigan
Orlando Science Center
St. Petersburg (FL) Junior College
St. Thomas University
St. Thomas University Library
Saint Petersburg Public Library
Science Library, University of Chicago
University of Miami
University of North Carolina at Wilmington

Membership applications, subscriptions, renewals, and changes of address should be addressed to the Executive Secretary, Florida Academy of Sciences, Orlando Science Center, 777 Princeton St., Orlando, FL 32803.

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 University Blvd., Melbourne, FL 32901-6975 [(407) 768-8000, ext. 8196; e-mail rturner@fit.edu].

PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Prices quoted include domestic postage. Some issues may not be available. All are $20 per volume or $5 per issue, except for symposium issues.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES (1936–1944)
  Volumes 1–7
QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCE (1945–1972)
  Volumes 8–35
FLORIDA SCIENTIST (1973–)
Florida's Estuaries—Management or Mismanagement?—Academy Symposium
  FLORIDA SCIENTIST 37(4)–$5.00
Land Spreading of Secondary Effluent—Academy Symposium
  FLORIDA SCIENTIST 38(4)—$5.00
Solar Energy—Academy Symposium
  FLORIDA SCIENTIST 39(3)—$5.00 (includes do-it-yourself instructions)
Anthropology—Academy Symposium
  FLORIDA SCIENTIST 43(3)—$7.50
Shark Biology—Academy Symposium
  FLORIDA SCIENTIST 45(1)—$8.00
Future of the Indian River System—Academy Symposium
  FLORIDA SCIENTIST 46(3/4)—$15.00
Second Indian River Research Symposium—Academy Symposium
  FLORIDA SCIENTIST 53(3)—$15.00

Please send payment with order. If required, an invoice will be sent on purchases over $20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.

6F63
H

61st ANNUAL MEETING

FLORIDA SCIENTIST

Program Issue

ISSN: 0098-4590

Volume 60 Supplement 1

SMITHSONIAN
MAY 16 1997
LIBRARIES

FLORIDA ACADEMY OF SCIENCES
1996-97 OFFICERS

PRESIDENT: DR. DAVID BLACK, South Florida Water Management Dist.
PRESIDENT-ELECT: DR. M. YASAR ISCAN, Florida Atlantic University..
PAST PRESIDENT: DR. LISA BEEVER, Charlotte Metropolitan Plan. Org.
PAST PRESIDENT: DR. PATRICIA DOORIS, Saint Leo College.
SECRETARY: DR. RICHARD MARCH, South Florida Water Mgt. District.
TREASURER: MS. GEORGINA WHARTON.
COUNCILLORS-at-LARGE
Mr. Al Kinlaw
Mr. David Sumpter, HDR Engineering, Inc.
Dr. William Trantham, Florida Keys Community College
Mr. Barry Wharton, HDR Engineering, Inc.
EXECUTIVE SECRETARY: MS. GERALYN HEARTZ, Florida Academy of Sciences.
CO-EDITORS, *FLORIDA SCIENTIST*: MS. BARBARA MARTIN, DR. DEAN F. MARTIN, University of South Florida.
BUSINESS MANAGER, *FLORIDA SCIENTIST*: DR. RICHARD TURNER, Florida Institute of Technology.
CO-PROGRAM CHAIRS: DR. GEORGE DOORIS, DR. PATRICIA DOORIS, Saint Leo College.
LOCAL ARRANGEMENTS CHAIR (1997 meeting): DR. LYMAN O'NEAL, Edison Community College-Punta Gorda.
JUNIOR ACADEMY OF SCIENCES CO-ORDINATOR: MS. KATHY GOTSHALL, Melbourne Central Catholic High School.

SECTION CHAIRS

Agricultural and Natural Resource Sciences: Dr. David Prichard, Univ. of Florida.
Anthropological Sciences: Dr. Wm. Jerald Kennedy, Florida Atlantic Univ.
Atmospheric and Oceanographic Sciences: Dr. Gary Zarillo, Florida Institute of Technology.
Biological Sciences: Michael Batts, Phoenix Environmental Group.
Computer/Mathematical Sciences: Dr. Daryl Schrader, St. Petersburg Junior College.
Engineering Sciences: All Hall, City of Talahassee.
Environmental and Chemical Sciences: Barbara Martin, University of South Florida.
Florida Committee on Rare & Endangered Plants & Animals: Rosemarie Mulholland, Florida Park Service.
Geology/Hydrology: Dr. Jon Arthur, Florida Geological Survey.
Medical Sciences: Dr. Allen Smith, Barry University.
Physics and Space Sciences: Dr. Mark Moldwin, Florida Institute of Technology.
Science Teaching: Dr. Jan Ems-Wilson, Valencia Community College.
Social Science: Dr. Maribeth Durst, Saint Leo College.
Urban & Regional Planning: Dr. Richard March, South Florida Water Management District.

1997 PROGRAM ISSUE

THE SIXTY-FIRST ANNUAL MEETING OF THE FLORIDA ACADEMY OF SCIENCES
in conjunction with the
Florida Junior Academy of Sciences
and the Science Talent Search

Featuring
A Symposium on the Sunshine State Standards' Impact on Introductory College
Science Courses by the
Coalition for Science Literacy
&
Two Plenary Addresses:

From Scrub to Sea: Natural Habitats of the Greater Charlotte Harbor Ecosystem
by Dr. James Beever
&
Syndrome X: Linking Early Life Malnutrition with Later Life Chronic Diseases
by Dr. Leslie Sue Lieberman

EDISON COMMUNITY COLLEGE
PUNTA GORDA
March 13-15, 1997

FLORIDA SCIENTIST
Volume 60 Supplement 1

ISSN: 0098-4590 Price: $4.00

published by the Florida Academy of Sciences
P. O. Box 033012, Indialantic, FL 32903-0012

third permanent campus, the Charlotte County Campus, in Punta Gorda.

ECC receives its funding primarily from the State of Florida. Student fees and federal grants provide approximately one-third of the college budget, with individual and private grants supplementing the nearly two-thirds provided by state sources. The ECC Community College Foundation, Inc., provides more than $500,000 per year in aid to ECC students and programs.

ECC is governed by its District Board of Trustees composed of nine representatives of Charlotte, Collier, Hendry, Glades and Lee Counties. The members are appointed to four-year terms by the Governor of Florida. Currently about 350 professional and support staff members provide the full-time instructional and related services for the more than 10,000 credit and 12,000 non-credit students who participate in ECC courses and programs each year.

REGISTRATION

ALL PARTICIPANTS ARE EXPECTED TO REGISTER. Academy members receive the Program Issue by mail in advance, as will nonmembers who register before February 7, 1997. Additional meeting material (including programs for individuals registering after 2/7/97) will be available at the registration desk.

LODGING

No reservations can be made through the Academy. The Academy has selected a host hotel as the center of activities for the meeting. This hotel has agreed to the special conference rates shown if you identify yourself with the Florida Academy of Sciences. Other hotels are available and are listed below.

Host Hotel: Holiday Inn, US41 northbound, on the Peace River. (941) 639-1165. $77 for waterview or $69 for parking lot view. After February 28, 1997, rates increase to $99.00 plus tax. 10% discount for AAA or AARP membership (off $99.00 rate only).

Other Hotels in Punta Gorda: All rooms: add tax to listed costs. Prices are quoted in anticipation of March and may not be as listed here. Be sure to reserve ASAP.

Howard Johnson's, US41 southbound, on the Peace River. (941) 639- 2167 or 1-800-446-4656. Waterside, $95/dbl. occ. or Parking lot side $85/dbl. occ.

Days Inn, exit 28 (Jones Loop) off I-75. (941) 637-7200. Standard room $64 / Poolside $69 dbl. occ.

Motel 6, 9300 Knights Drive, Exit 28 (Jones Loop) off I-75. (941) 639-9585. $50/sgl. or dbl. occ.

Knights Inn, 1520 Tamiami Trail, Punta Gorda. (941) 639-8000.$45/sgl. occ. or $50/dbl. occ.

Sea Cove Motel, US17 south. (941) 639-0060. $46/standard room with one double bed.

Harbour Inn, 5000 Tamiami Trail, Charlotte Harbor. (941) 625-6136. $50/dbl. occ.

Fisherman's Village, 1200 W. Retta Esplanade, Punta Gorda. (941) 639-8721. On the River - two bedroom apt. w/loft, kitchen, dining room, 1 bath, balcony. Sleeps 6. $100/night or $600/week.

KOA Campground, 6800 Golf Course Blvd. (941)637-1188. Log Cabins $33.95/couple or $41.75 with two bunks, bring your linens. Tents $22.35 and RV full hook-up $26.45.

FRIDAY'S LUNCHEON & BANQUET

A box lunch on Friday, March 14, is included in the Meeting registration fee.

The Academy Banquet will be held on Friday evening (March 14) at the Holiday Inn at 7:30pm. The dinner will be a choice of Chicken Cordon Blue, London Broil or Vegetable Quiche. All entrees are served with a tossed salad, vegetable, potato, rolls and butter, coffee, tea, decaf and dessert. Only a few tickets will be available on the day of registration, and preregistration for the banquet is suggested. The banquet will be preceeded by a sunset cruise and social at 5:30pm. Cost of the banquet does not include the cost of the cruise.

Information on restaurants in the area will be available at the registration desk.

MEDALIST PRESENTATION

Dr. Leslie Sue Lieberman, 1996 Academy Medalist, will present the Annual Medalist Lecture immediately after the Banquet. The title of this lecture is “Syndrome X: Linking Early Life Malnutrition with Later Life Chronic Diseases.”

ACADEMY PLENARY SESSION & BUSINESS MEETING

The Plenary address by Dr. James Beever entitled “From Scrub to Sea: Natural Habitats of the Greater Charlotte Harbor Ecosystem” will be presented at 1:00 pm in the Auditorium. It will be preceded by the Annual Business Meeting chaired by Dr. David Black, President.

SOCIAL EVENTS AND FIELD TRIPS

A number of social events and field trips are available during the

Meeting. Further information will be available at the registration desk.

Thursday, March 13, 1997

1. Cabbage Key field trip (10:00 am). Cost: $18.00
2. Charlotte Harbor Environmental Center (10:00 am). Cost: free
3. Babcock Wilderness Adventures (10:00 am). Cost: $16.00
4. Punta Gorda Historic Walk (10:00 am). Cost: free
5. Reception Bar-B-Q at Babcock (6:00 pm). Cost: $12.50. (Reservations required. Contact Local Arrangements Chair).

Friday, March 14, 1997

1. Sunset cruise social, hors d'oeuvres, cash bar (5:30 pm). Cost: $12.00

Other places of local interest::

1. Edison Home. Cost: $ 7.00
2. Edison and Ford. Cost: $ 8.50
3. Sea Kayaking (details provided)

LOCAL ARRANGEMENTS

The Local Arrangements Chair for this Meeting of the Academy is Dr. Lyman O'Neal of Edison Community College (941-639-3822, fax 941-575-4525, email loneal@sunline.net). He may be consulted for any special meeting needs. Dr. O'Neal is ably assisted by the Local Arrangements Committee:

James Beever
Lisa Beever
Joy Duperault
Joseph Hart
George Manacheril
Wiliam Wilcox.

FLORIDA JUNIOR ACADEMY OF SCIENCES

The Florida Academy of Sciences will meet with the Junior Academy, the student branch of FAS. Florida Junior Academy of Science (FJAS) encourages the growth of our junior and senior high school science students science by allowing them to compete, share, and network with other students and adults having a common interest in science and research activities. Annual events encourage student research, sharing of research in a "real life scientist" format, and interacting with adult role models. FJAS seeks volunteers to assist in judging and acting as section moderators at its meeting to be held on Saturday afternoon (March 15). Persons interested in participating in this rewarding experience should contact the FJAS Coordinator: Mrs. Cathy Gotshall, Melbourne Central Catholic High, 100 E. Florida Ave., Melbourne, FL 32901, (407) 727-0793.

COMMERCIAL AND INSTITUTIONAL EXHIBITS

Space is available on a first come-first served basis for a fee of $75.00. Exhibits by research institutions or Programs and others of an informational nature may be given free space. Parties interested in fee or free spaces should contact the Local Arrangements Chair for details.

STUDENT AWARDS

Students presenting papers at the Annual Meeting of the Academy and who are registered for the Meeting may be considered for a number of awards. Details are presented below, and further information may be obtained from Dr. Daryl Schrader, Awards Committee Chairman (813-341-4605).

1. Outstanding Student Paper Award - This award is presented by any of the Academy Sections to graduate and/or undergraduate students.

2. American Association for the Advancement of Science Award - This award is presented to one male and one female undergraduate student annually and is a one-year membership in AAAS including the journal, *Science*.

3. Explorer's Club Award - This prize of $300 is awarded for the "most original research paper" furthering the goals of the Club in scientific exploration. The prize is awarded to graduate students and the paper must be presented again at the Explorer's Club banquet in Orlando in May.

4. Sigma Xi Awards - The first award, presented by the University of Florida chapter of Sigma Xi, is for $50 and a plaque. The award is presented to graduate students. The second award is presented by Florida Institute of Technology for the best paper by an FIT student. The award is for $50.

5. William W. Behrens, Jr./Florida Institute of Oceanography Award - This $750 prize is awarded by the Florida Institute of Oceanography to an undergraduate or graduate student for the best paper in any area of ocean or marine sciences.

ANNOUNCEMENTS

1. 1998 ANNUAL MEETING: The 1998 Annual Meeting is tentatively planned for the new home of FAS, the new Orlando Science Center. Details will follow in FAS Newsletter and the 1998 Call for Papers.

2. NEW EXECUTIVE SECRETARY: Ms. Geralyn Heartz has joined FAS as our Executive Secretary. Her office is located in the Orlando Science Center.

3. NEW PERMANENT OFFICES FOR THE ACADEMY: The FAS office has been re-located to the new Orlando Science Center. The address and telephone number are shown below. FAX and e-mail connections are planned, and this information will be forwarded to members as soon as it is available.

Florida Academy of Sciences
Orlando Science Center
777 East Princeton St.
Orlando, FL 32803
407-514-2079.

4. The National Estuary Program is holding a symposium on Charlotte Harbor, as described in this program. The symposium is being held at the Holiday Inn, and it is open to all without additional charge. FAS participants are urged to attend the Saturday (March 15) and the Sunday (March 16) sessions.

5. PROGRAM NOTES:

1. A presentation on "Florida House" will be held in the Engineering Science Section on Friday, March 14, at 4:00 pm, in Room 210 (p. 17).

2. A new video on Florida Geology will be shown in the Geological and Hydrological Sciences on Friday, March 14, at 3:45 pm, in Room 109 (p. 31).

FLORIDA ACADEMY OF SCIENCES
1997 ANNUAL MEETING PROGRAM SUMMARY

THURSDAY, MARCH 13

TIME	EVENT
10:00 am	**Field Trips** Babcock's Wilderness Adventures Cabbage Key Charlotte Harbor Environmental Center Punta Gorda Historic Walk
3:00 pm	FAS Council Meeting, ECC, Rm. 101
6:00 pm	Bar-B-Q, Babcock's

FRIDAY, MARCH 14

TIME	EVENT
7:30 am-5:00 pm	FAS Registration & Information Desk, ECC Classroom Bldg., 2nd Floor Lobby
8:00 am-11:30 am	FAS Concurrent Paper Sessions, ECC Classroom Building, Various Rooms
11:30 am-12:30 pm	Box Lunch Served, ECC Student Activities Building
12:30 pm-1:00 pm	FAS Business Meeting, ECC Auditorium
1:00 pm-1:45 pm	Plenary Address, Dr. James Beever, ECC Auditorium
2:00 pm-5:00 pm	FAS Concurrent Paper Sessions & Symposium, ECC Classroom Building, Various Rooms
5:30 pm-6:45 pm	Sunset Cruise, Holiday Inn Dock
7:30 pm	FAS Banquet & Medalist Address, Holiday Inn

PROGRAM SUMMARY, CONTINUED

SATURDAY, MARCH 15

TIME	EVENT
10:00 am- Noon	FJAS Registration, Classroom Bldg. 2nd Floor Lobby
Noon-12:30 pm	FJAS Welcome & Opening Session, ECC Auditorium
12:30 pm-1:00 pm	FJAS Briefing of Judges & Session Moderators
1:00 pm-5:00 pm	FJAS Concurrent Paper Sessions, ECC Classroom building, Various Rooms
8:00 pm	FJAS Awards, ECC Auditorium
8:00 am-5:00 pm	National Estuary Program's Charlotte Harbor Symposium, Holiday Inn

NOTES: 1. FAS refers to the Florida Academy of Science; FJAS refers to the Florida Junior Academy of Science.
2. Please see Detailed Program for locations of paper sessions.
3. The Charlotte Harbor Symposium if open to all at no cost.

AGRICULTURAL AND NATURAL RESOURCE SCIENCES

FRIDAY 9:00 AM , ROOM 102 in Classroom Bldg.
Section Meeting: Agricultural and Natural Resources Sciences
David Prichard, University of Florida, Presiding

ANTHROPOLOGICAL SCIENCES

FRIDAY 8:30 AM, ROOM 203 in Classroom Bldg.
SESSION A: BIOLOGICAL ANTHROPOLOGY
Wm. Jerald Kennedy, Florida Atlantic University, Presiding

8:30AM ANT-1 Periodontitis among Pre-contact South Florida Indians. JULIUS N. OBIN, MORTON H. KESSEL AND MEHMET YASAR ISCAN, Florida Atlantic University, Boca Raton 33431. There is a controversy as to whether or not periodontitis is an ancient disease affecting all cultural groups. Because it is difficult to find a human population without generalized periodontal disease, it is usually necessary to have recourse to the jaw remains of ancient groups which had masticated natural unrefined foods throughout life. The purpose of this presentation is to describe the signs of periodontitis on the alveolar process thus enabling one to determine whether or not the disease was present in prehistoric skeletal populations. The dentition of Archaic Indian population (Republic Groves, 8HR4, 2000 BC) has been investigated in terms of dental disease affecting both the teeth and the alveolar bone. All of the teeth displayed marked wear of enamel, including perforated occlusal sites causing alveolar manifestations of pulpits. Of particular interest is the minimal evidence of periodontitis; one individual is so diagnosed. This individual displayed the necessary criteria of periodontitis. These are the loss of the surface cortical bone with exposure of the underlying porous cancellous interproximal bone and rounded margins of crestal bone.

8:45AM ANT-2 Expressions of Sexual Dimorphism in the Lower Extremities of South African Blacks. M. YAŞAR IŞCAN AND MARY BARBOT ALLEN, Florida Atlantic University, 777 Glades Rd., Boca Raton, FL 33431. The purpose of this paper is to gauge sexual dimorphism in South African Blacks and to test the results of this study against current standards for American Blacks. Of particular importance are those bones which meet two criteria: namely, endurance and integrity in the face of elemental exposure and fragmentation, and sexual dimorphism. Select sites from the femur and tibia have been chosen accordingly. Osteometric analyses were performed on the Raymond Dart skeletal series housed by the University of Witwatersrand in South Africa. Out of a collection of 3,000 skeletons of known origin, a total of 90 individuals were examined and measured by the senior author. Subsequently all data was entered into SPSS-X for discriminant function analysis. From the tibia and femur 13 variables were chosen and compared with corresponding standards for American Blacks. Results of this study indicate that a certain ranking of variables exists, and that depending upon the long bone chosen, sex may be classified accordingly.

9:00AM ANT-3 Metric Analysis of Sexual Dimorphism in the Humerus of South Asians. C.A. KING, S.R. LOTH, AND M.Y. IŞCAN, Florida Atlantic University, Boca Raton, FL 33431. Recent advances in forensic anthropology have shown that osteometric-based sex determination techniques must be developed for geographically diverse populations using contemporary skeletal material. The purpose of this paper is to assess sex differences in the south Asian humerus. The sample consisted of 181 adult skeletons of known age and sex from Chiang Mai University, Thailand, and the University of Hong Kong. A total of 7 variables were subjected to SPSSX subroutines. Because no significant differences were found between the two samples, they were combined. Stepwise discriminant analysis chose the optimal combination of dimensions, and the direct method evaluated measurements, singularly, and in combination. Vertical head diameter, minimum shaft diameter, and epicondylar breadth were selected by the stepwise procedure as the most discriminating variables resulting in 92.5% classification accuracy. The direct assessments developed functions from individual and combined variables to analyze fragmentary remains, and yielded accuracies ranging from 80.7% to 91.9%. These results are on a par with lower extremity bones from the same populations.

9:15AM ANT-4 Mandibular Ramus Flexure in Modern and Fossil Hominids. S.R. LOTH (1), and M. HENNEBERG (2), (1) Florida Atlantic University, Boca Raton, Florida 33431, (2) Department of Anatomy, University of Adelaide Medical School, Adelaide, Australia. The overlap of male and female size differentials in the skeleton, variation across populations and over time, limit the usefulness of metric methods to determine sex. Morphologic differences, however, that are recognizable over time and across populations and species should lead to more reliable separation of the sexes. This paper presents just such a new morphologic indicator of sexual dimorphism (Loth and Henneberg, 1996). The sample consisted of 547 mandibles from adults of known sex, representing Africans, American whites, blacks and Amerinds from the Dart and Smithsonian

Collections. In adult males, there was a distinct angulation of the posterior border of the mandibular ramus at the level of the occlusal surface of the molars. In most females, the posterior border of the ramus retained the straight juvenile shape or if flexure was noted, it was either higher (at the neck of the condyle) or lower, in association with gonial eversion. Prediction accuracy ranged from 91% to 99% for subsamples of each population and surpassed 94% for the entire sample. Observations of fossil hominids and casts from australopithecines through early moderns revealed the same configurations. In conclusion, sexing accuracy from ramus flexure is on a par with that from a complete pelvis. Its effectiveness stems from its origins as a male developmental trait only manifest consistently after adolescence and maintenance by optimal balance of the muscles of mastication.

FRIDAY 9:30 AM, ROOM 203 in Classroom Bldg.
SESSION B: CULTURAL/ETHNOHISTORIC ANTHROPOLOGY
Wm. Jerald Kennedy, Florida Atlantic University, Presiding

9:30AM ANT-5 Empowered or Pressured? A Woman's Political Struggle in a Rural Mayan Community. D.M. GUTIERREZ, Florida Atlantic University, Boca Raton 33431. Based on fieldwork conducted in a rural community in Yucatan, Mexico, an ethnographic insight into a woman's political involvement and the risks of her involvement is provided. The influence of her family and friends on the extent of her political participation and the consequences of her participation as it affects her, her family, the community, and the state is further explored. How the political policies can create conditions within which women make decisions which shape their conceptions of politics is also shown.

9:45AM ANT-6 Bringing down the light: A study of a New Age millenarian group. NOAH TEITELBAUM. New College, 5700 N. Tamiami Tr., Sarasota 34243. "Ashtar 101," like all millenarian groups, is expecting and preparing for the world to change drastically though divine intervention. This group, one of many chapters in an international network, focused on channeled messages that reveal the true history of the earth as well as the upcoming arrival of angels, aliens, genetic regeneration, personal flying scooters and an overall spiritual utopia. These were all to follow the landings that were supposed to have happened before the 17th of Dec. 1996. After a description of the group and their beliefs there will be a discussion of different approaches to millenarian studies and finally an exploration of Ashtar 101's paradox, self-will vs. surrender to divine fate, in relation to the interaction between Clifford Geertz's religious models *of* and *for* the world.

10:00 AM BREAK

10:15AM ANT-7 Approaches to the Study of the Shaman. S. L. SELKA, JR., Florida Atlantic University, P.O. Box 3091 Boca Raton 33431. A recent resurgence of interest in the shaman is noted, and several problems and questions in the study of shamanism are examined. These include whether it is justified to view the role of the shaman as a cross-cultural phenomenon capable of being defined in terms of common elements and characteristics; the question of the "sanity" or relative "normality" of the shaman and the concept of the shaman as a "neurotic" or as a "pathological" individual; and if a productive investigation of the process and significance of the practice of "shamanism" should focus on the individual experience and psychology of the shaman or rather on the functions and relationships of the shaman in the broader social context. Viewpoints of a wide array of scholars and researchers, ranging from experimental psychologists to anthropologists, are introduced, analyzed, and synthesized where possible. It is concluded that an analytically useful definition that captures the important features of the shaman cross-culturally is possible, and such a definition is introduced; the shaman is not a "madman" but an individual that lives a culturally constructed and approved life; and that a holistic approach to the study of the shamnan that is well grounded in ethnographic observation is needed.

10:30AM ANT-8 Archaeological and Historical Analysis of Arthur, 'King of the Britons.' N. LABOS, Florida Atlantic University, Boca Raton 33431. The controversy surrounding the historical figure of King Arthur resides chiefly in the legends which are associated with him. For many decades the figure behind these legends was ignored and given little scholarly attention. Only in recent years have any efforts to discern the Arthur of fact from the Arthur of fiction been made. The purpose of this paper is to discuss a research proposal to better understand his historical and political contributions to Britain, and the impact his leadership had on subsequent generations. His brief reign had such a tremendous influence on his contemporaries that they expanded his image into heroic proportions. Any further developments in this area can only be determined by the relation of historical facts to archaeological evidence dating back to the fifth century when Arthur ruled post-Roman Britain. A comparison is made with known archaeological sites and historical sources (including original manuscripts). The weapons, armor, battles and foreign policy of Arthur's military leadership as well as the remnants of Roman civilization, which primarily affected the government and politics of the tumultuous period are discussed.

10:45AM ANT-9 Indications of Cultural Change in Early Eighteenth Century Georgia. DANIEL HUGHES.Anthro. Dept, Florida Atlantic Univ., 777 Galdes Road, P.O. Box 3091, Boca Raton, Fl 33431-0991. Just prior to the American Revolution a changing set of cultural values were taking place in the colonies. The colonists were acting upon desires to be free from the control of a culture with whom they had lost touch. No longer did colonists feel they should be treated as lesser citizens of England. The development of a large merchant class equal in wealth to many members of the aristocratic class led to changing levels of status and equality in the colonies. The goal of this paper is two fold. The first is to show how historical documents can be used to test anthropological theories of cultural change. The second is to prove that combinations of distance from strong power centers of English authority and environments with limited resources on the edge of the colonial frontier, allowed individuals to express feelings of equality to those stationed above them by birth. The paper shall document a period in the life of Andrew Duche, a potter in Savannah, Georgia who resisted both local authority and the Trustees of the Georgia colony. He is an example of the changing cultural value system that would sweep the colonies in the years prior to the Revolution.

11:00AM ANT-10 God and God the Despot: A Cognitive Approach to Anthropomorphism and Dogmatism in Early Islamic Theology. KAMAL FERIALI. University of Florida, Department of Anthropology. A cognitive approach to religious thought is not only legitimate, but is dictated by the nature of religion itself. Although religious belief may be shaped by various ecological, political, economic and historical particularistic factors, it remains, in essence, a mental function and, therefore, a product of the human mind and is limited by its constraints. It is from this perspective that I approach the issue of the anthropomorphization of the deity, particularly in Islam, and how anthropomorphizing relates to dogmatism. I argue that religious dogmatism is essentially a cognitive process which may be systematically outlined using cognitive findings in anthropology, psychology, linguistics and religious thought itself. At the core of religion, the idea of a "transcendent" God can be discerned. This abstraction, however, is often cognitively optimized through its endowment with human-like characteristics. It is when this transformed entity is espoused at some point and the original "transcendent" one slips into oblivion, that a form of what we call "religious dogmatism" evolves.

11:15AM ANT-11 The Ultimate Cup of Joe: An Interdisciplinary Examination of Black Drink. REBECCA L. JACOB Dept. of Anthropology, 777 Glades Road Boca Raton 33486, Florida Atlantic University. Historical accounts of the early European contact period in the New World describe the use of stimulants by aboriginal people. Eyewitness accounts recorded by Spanish and other European explorers have provided the archaeologist and the ethnohistorian tantalizing evidence that have aided in identifying certain items of material culture associated with the ceremonial usage of stimulants. For years, archaeologists in the Southeast have recognized paraphernalia associated with the ceremonial aspects of stimulant use. In more recent years, techniques have been developed in order to examine residues left on these artifacts. Paleoethnobotanists have also looked for botanical remains that would confirm the use of Yapon Holly or *Ilex vomitoria, Ilex cassina*, and other varieties of this emetic that make up the concoction called black drink.

FRIDAY 2:00 PM, ROOM 203 in Classroom Bldg.
SESSION C: ARCHEOLOGY
Wm. Jerald Kennedy, Florida Atlantic University, presideing

2:00PM ANT-12 Finger mounds: A Circum-Glades Phenomenon. MORTON H. KESSEL AND MEHMET YASAR ISCAN. Mounds of a characteristic style, with an architectural and artistic similarity are unique to south Florida. Located in the area around lake Okeechobee and nowhere else, they offer an insight into cultural tradition, the lifeways and the cognitive processes of the builders. These atypical earthworks, decribed elsewhere as circular-linear, and named here with the more descriptive term "finger mounds", are examined spatially and temporally to distinguish them from purely circular or purely linear erathwork mounds.

2:15PM ANT-13 Aboriginal Canoe Canals of Cape Sable, R. J. WHEELER, C.A.R.L. Archaeological Survey, Bureau of Archaeological Rsch., 1625 NW31st Place, Gainesville, FL, 32605. The Mud Lake and Snake Bight canals were dug by Indians to facility canoe travel between Whitewater Bay and Florida Bay. Like other prehistoric long distance canals in Florida these features were designed to provide safe passage, easy access to aquatic resources, and courses for exchange or tribute. John K. Small, pioneer naturalist, provided the first scientific description of the Mud Lake Canal, noting its proximity to the Bear Lake Indian mounds. Using older descriptions and aerial photographs the courses of both canals have been partially reconstructed. It is hypothesized that the Snake Bight Canal is the older of the pair, and may have been damaged by a hurricane; the Mud Lake Canal was built to replace the damaged canal. Both canals would have allowed the inhabitants of the Bear Lake Mound group to control. canoe traffic moving between southeastern Florida, the Florida Keys, and the Ten Thousand Islands.

2:30PM ANT-14 The Role of Environmental Archaeology in. Studies of Global Climatic Change: A Charlotte Harbor Case Study, K. J. WALKER

AND W. H. MARQUARDT, Florida Museum of Natural History, P. O. Box 117800, Gainesville 32611. We present archaeological and geological evidence for small-scale, Late Holocene sea-level fluctuation along Florida's Gulf coast, primarily based on data generated in Charlotte Harbor but also from northwest Florida. Drawing data from archaeological middens, zooarchaeological gradient analysis of modern and archaeological mollusks, and independent dating of sediments along the barrier islands undertaken by Frank Stapor and his associates, we propose a model of Florida Gulf coast sea level: (1) 40 to 60 cm below today's mean sea level (MSL) prior to A.D. 100; (2) a rise to present MSL ca. A.D. 100-200; (3) 70 to 130 cm above present MSL ca. A.D. 200-500; and (4) a fall to a low of at least 50 cm below today's MSL by A.D. 600. These fluctuations can be correlated with global climatic episodes documented by climatologists. With the exception of locations dominated by alluvial processes, the Gulf coast -- especially the Charlotte Harbor Estuarine System -- is an excellent laboratory for the interdisciplinary study of global climatic change.

FRIDAY 2:45PM, ROOM 203 in Classroom Bldg.
SECTION MEETING: ANTHROPOLOGY
Wm. Jerald Kennedy, Florida Atlantic University, Presiding

ATMOSPHERIC AND OCEANOGRAPHIC SCIENCES

FRIDAY 10:00 AM, ROOM 210 in Classroom Bldg.
SECTION MEETING: ATMOSPHERIC AND OCEANOGRAPHIC SCIENCES
Gary Zarillo, Florida Institute of Technology, Presiding

BIOLOGICAL SCIENCES

FRIDAY 8:30 AM, ROOM 201 in Classroom Bldg.
SESSION A
Walter E. Meshaka, Jr., Presiding

8:30 AM BIO-1 Species Composition of Mollusks and Polychaetes in Hillsborough Bay, 1963 vs. 1993-1995. DAVID J. KARLEN (1), STEPHEN A. GRABE (1), THOMAS PERKINS (2), WILLIAM LYONS (2), AND GREGORY BLANCHARD (3), (1) Environmental Protection Commission of Hillsborough County, 1410 N. 21st. Street Tampa 33605, (2) Florida Marine

Research Institute, 100 8th Ave. SE St. Petersburg 33701, (3) Manatee County Environmental Management Dept. POB 1000 Bradenton 33506. Comparisons of the mollusk and polychaete fauna of Hillsborough Bay from a 1963 National Marine Fisheries Service survey and the current Tampa Bay National Estuary program benthic monitoring program are made on the basis of species richness, evenness, and presence-absence. Although some discrepancies between the two surveys can be ascribed to differences in study design and methodology, where alterations in bay habitat or the ecology of certain species may contribute to differences, these are addressed.

8:45AM BIO-2 Lab feeding preferences in the sea urchin *Lytechinus variegatus* for the seagrasses *Thalassia testudinum* and *Syringodium filiformes*. L.M. WILLIAMS (1) and J.R. MONTAGUE (2), (1) Biology Department, Florida A&M University, Tallahassee, FL 32307, (2) SNHS, Barry University 11300 NE 2nd Avenue, Miami Shores, FL 33161. Two replicate feeding tests with adult sea urchins were conducted in 20-liter sea water tanks (25°C) during Summer 1996. The urchins were starved for 48 hours, and then offered equal proportions of green and decayed blades of T. testudinum and S. filiformes; the exposed blades (5-cm) were attached to nylon rope buried in sand. The urchins consumed the blades in equal proportions, and displayed no apparent preference for any particular blade type. This probably represents the general foraging behavior expected for herbivores which face relatively low energetic costs during travel but relatively high energetic costs during digestion. (Supported by U.S. Army Corps of Engineers Award DACW39-94-K-0032, and CMEA of Rosenstiel School of Marine and Atmospheric Science at the University of Miami).

9:00AM BIO-3 Chemical compositions in green and decayed portions of the seagrasses *Thalassia testudinum, Syringodium filiformes, and Halodule wrightii.* L.M. WILLIAMS (1), M. MESADIEU (2), A. MORALES (2), AND J.R. MONTAGUE (2), (1) Biology Department, Florida A&M University, Tallahassee, FL 32307, (2) SNHS, Barry University 11300 NE 2nd Avenue, Miami Shores, FL 33161. Above-sediment tissues of attached T. testudinum, S. filiformes, and H. wrightii were harvested from three sites in Biscayne Bay in Summer 1996; these were cut and sorted into qualitative categories of green, semi-decayed, and fully-decayed blades. Dry-weight analyses showed variabilities in water content among the three species. Carbon-nitrogen analysis showed that C:N molar ratios in decayed tissues were significantly higher than for green or semi-decayed tissues. There were also variabilities among the three species in percent-organic content and protein content. (Supported by NIH MARC grant and Barry University, U.S. Army Corps of Engineers Award DACW39-94-K-0032, and CMEA of Rosenstiel School of Marine and Atmospheric Science at the University of Miami).

9:15AM BIO-4 Measures of biomass and productivity in the seagrass *Thalassia testudinum* for three sites in Biscayne Bay. A. MORALES, R.K. BELLABE, M. RUDINSKY, G. LEWIS, S. CORREA, AND J.R. MONTAGUE, SNHS, Barry University 11300 NE 2nd Avenue, Miami Shores, FL 33161. Above-sediment tissues of attached T. testudinum, Syringodium filiformes, and Halodule wrightii were harvested from three sites in Biscayne Bay over a two-year period. T. *testudinum* was the most abundant species at two of the sites (along the bayside of Key Biscayne and Virginia Key), while S. *filiformes* was most abundant at the third site (along the ocean side of Key Biscayne). Samples of T. testudinum shoot productivity at each site were collected in Summer 1996; the sample shoots showed a mean growth rate of roughly 8-10 mm/day during July-August. (Supported by NIH MARC grant and Barry University, U.S. Army Corps of Engineers Award DACW39-94-K-0032, and CMEA of Rosenstiel School of Marine and Atmospheric Science at the University of Miami).

9:30AM BIO-5 Thermoregulation and the Effect of Body Temperature on Call Parameters in the Cicada *Diceroprocta olympusa* (Homoptera: Cicadidae). ALLEN F. SANBORN AND SAMANTHA MATE NANKERVIS, Barry University, School of Natural and Health Sciences, 11300 N.E. Second Avenue, Miami Shores 33161. Temperature effects all aspects of a cicada's life, from the rate of neural firing to signaling when a population will emerge. Ectothermic animals must regulate body temperature to maximize physiological efficiency under changing environmental conditions. This is especially important in acoustically signaling organisms whose mate attraction system may be altered by temperature. With this study we investigate the thermoregulatory strategy of *Diceroprocta olympusa* (Walker) and try to determine if the temporal parameters of the calling song are correlated with body temperature. We found that *D. olympusa* regulates body temperature through behavioral mechanisms. Analysis of the calling song shows the call is a constant frequency call produced by a repetition of sound pulses. Mean peak frequency of 10,123 + 1,113 Hz (n=34) is a result of the physical structure of the sound producing system. The timbals contract alternately and a single timbal contraction produces a main pulse produced as the timbal plate buckles followed by three smaller pulses as the timbal ribs buckle. Individual sound pulses are produced at a rate of 94.88 + 4.82 Hz (n=34). We found that pulse rate was correlated to body temperature.

9:45AM BIO-6 Implications of Nonanthropogenic Sources of Fecal Coliform Bacteria in Natural Waters in Northeast Florida. V.J. HARWOOD, K. STOOK, R. O'TOOLE, S. AGARWAL AND V. WAGNER. Department of Natural Sciences, University Of North Florida, 4567 St. Johns Bluff Rd. South, Jacksonville, FL 32224-2645. Water samples were collected from the Guana River Wildlife Management Area in St. Johns County, and assayed for total and fecal coliform bacteria. Five percent of positive fecal coliform samples were further analyzed for the presence of *E. coli.* Samples routinely tested positive for fecal coliforms, but only a small percentage were identified as *E. coli.* In order to determine the possible nonwarmblood sources of bacterial contamination, the cloacae of diamondback terrapins collected from a nesting beach on the Nassau River (Duval County) were sampled for fecal coliform bacteria and *Salmonella* species. No positive results for *Salmonella* were obtained, however one turtle out of 26 (~4%) tested positive for fecal coliforms. Since fecal coliforms are the most widely used indicator organisms for human fecal pollution, and their presence has been used to close shellfishing beds in Duval and St. Johns County, a better understanding for the sources of contamination and the species represented by this group is necessary, as well as the establishment of additional water quality indicators which accurately reflect the potential for human illness.

10:00AM BREAK

10:15AM BIO-7 Field Testing Models of Intraspecific Nest Parasitism in Passerines. B. A. HAMILL, E. J. BIERHANZL, and D. J. MILINKOVICH. Departments of Biology and Economics, Florida A&M University, Tallahassee, FL 32307. The use of molecular measures of genetic relatedness have provided an intriguing view into the mating behavior of a number of species of monogamous passerines. Initially, studies focused on adult males raising genetically unrelated offspring resulting from cuckoldry. In this paper, however, we consider the consequences of intraspecific nest parasites. Egg-dumping by females results in both parents investing energy and resources in one or more genetically unrelated offspring. Reports suggest rates of intraspecific parasitism ranging from <2% to over 20% among different populations of Eastern Blue Birds (*Sialia sialis*).The cost of rearing altricial young would seem to select against parents that squandered their energy/resources on genetically unrelated young. Conversely, selection should favor the female that not only raises a full clutch of her own, but is able to produce a additional young with the unwitting help of a neighbor. Using a regression-based model, we generate predictions on the costs, benefits, and occurrence of intraspecific nest parasitism under a variety of conditions. Among the variables considered are: clutch size, time of season, first or second clutch, age of female, territory quality, male attentiveness to nest, female attentiveness to nest, population density, and neighbor proximity. Preliminary results suggest that a number of factors interact to determine rates of parasitism within a population. Female attentiveness, measured as time at the nest, is inversely correlated with likelihood of being parasitized. The predictions generated by the model are currently being used to design field experiments. Blue bird nest boxes set up at two locations outside Tallahassee, FL allow an ideal situation to test various aspects of the model in the field.

10:30 BIO-8 Role of the Egg Capsule in Protection of Embryonic Applesnails from Ultraviolet Light. R. L. TURNER AND S. L. WILLIAMS, Department of Biological Sciences, Florida Institute of Technology, 150 West University Boulevard, Melbourne 32901-6975. The aquatic Florida applesnail, *Pomacea paludosa*, lays clutches of eggs on stems of emergent plants, where embryogenesis proceeds to hatching over a 2-wk period, during which the clutch is fully exposed to sunlight. Two components of the egg might provide protection to embryos from UV light (viz., UV-B, 280--320 nm): the extracapsular jelly and the calcareous capsule. Methanolic extracts of jelly did not absorb in the range of UV-B radiation nor in the range indicative of microsporine-like amino acids (MAA; 310--340 nm). Transmittance of light through hemispherical eggshells was reduced to 99.98% in the UV-B range. The Florida applesnail does not use biological sunscreens (MAA) in mucus as do many shallow-water marine invertebrates for UV-protection, but the thin (40-micron) calcareous capsule offers a high level of protection, perhaps through a combination of reflectance and absorbance. In addition, the early embryo might gain protection by the extraembryonic albumen and the late embryo by melanin formation and the body shell.

10:45AM BIO-9 Comparative Ecological Succession of the Former Ft. George Island Golf Course Fairways, Duval County. J. L. RANDALL, Department of Natural Sciences, University of North Florida, 4567 St. Johns Bluff Rd., Jacksonville, 32224. Natural ecological succession of the former Ft. George Island Golf Course fairways is examined after four years of abandonment. Three former fairways are compared in order to show the floristic similarities and differences in succession patterns among ecologically similar sites. Comparisons are based on species composition, density, frequency, and importance values. A qualitative, visual comparison is also made among one, three, and four year stages of succession. Methods for maritime forest restoration are also discussed.

11:00AM BIO-10 Development of a Natural Resources Management Plan for the Protected Area Network of the South Beaches, Brevard County, Florida. A. J. ZAHORCAK[1] AND H. M. SWAIN[2], [1] Florida Park Service, District 5, 13798 SE Federal Hwy., Hobe Sound, FL 33455, [2] Archbold Biological Station, PO Box 2057, Lake Placid, FL 33852. The Beaches of Brevard and Indian River Counties include a series of land parcels which are part of a regional protected area network (PAN), the Archie Carr National Wildlife Refuge (ACNWR). Utilizing Geographic Information System (GIS), and natural resource information (species, communities, landscape context), individual agency management information was evaluated. Recent conservation biology protocols for reserve design were modified for management planning to develop a coordinated natural resource management plan for the South Beaches PAN. A modified form of the minimal set algorithms technique (Nicholls and Margules 1993) and a modified form of gap analysis (Scott et al. 1990) were used to develop management recommendations for the South Beaches PAN.

11:15AM BIO-11 Presettlement Environments of the Lower Myakka River. B. WHARTON, HDR Engineering, 5100 W. Kennedy Blvd., Tampa 33609. The Myakka River was first explored in the 1500s and the first accurate navigational chart of the river was published in 1774. During Florida's territorial days, several exploration parties penetrated the Myakka River, most notably the John Lee Williams exploration (1828) and the Hackley-Murray-Prior expedition (1832), and left a tantalizing record of their observations. During early statehood, General Land Office surveyors laid out the current system of townships and sections across the region and documented in their field notes and plat maps a vast open pine and savanna landscape bisected by a picturesque river swathed in an oak-cabbage palm hammock. Analysis of this historical data distinguished three zones along the river corridor: (1) an upper freshwater zone with a narrow, well-incised river channel backed by a thin riparian oak-palm hammock, (2) an intermediate brackish water zone with a gradually widening river channel backed by a brackish marsh, and (3) a lower brackish water zone with a broad river channel backed by brackish marsh, and mid-channel mangrove islands and cedar islands. Despite considerable recent development, much of today's Myakka River corridor bears a striking similarity to its presettlement counterpart.

FRIDAY 11:30 AM, ROOM 201 in Classroom Bldg.
SECTION MEETING: BIOLOGICAL SCIENCES
Michael Batts, Phoenix Environmental Group, Presiding

FRIDAY 2:30 PM, ROOM 201 in Classroom Bldg.
SESSION B
Richard Turner, Florida Institute of Technology, Presiding

2:30PM BIO-12 Sleep Cycles of Apnea-Eupnea in the Southern Elephant Seal *Mirounga leonina*. S.M. BINGHAM (1), D. DE LAMO (2), M. LEWIS (2), AND V. FALABELLA (2), (1) Barry University, 11300 N.E. 2nd Ave., Miami Shores, 33161, (2) Centro Nacional Patagonico, s/$^{\underline{no}}$ Blvd. Brown, Puerto Madryn, Chubut, Argentina. The elephant seal of the south, *Mirounga leonina*, is found along the coast of Patagonia, Argentina. A major characteristic of elephant seals is their ability to maintain apneas for extended periods of time, both on land and in water. As they progress in age, changes in their apnea-eupnea cycling patterns are observed. It is hypothesized that these changes are in response to a greater demand for this trait as they advance from the land-living, non-diving pups to theocean-diving, food-foraging adults. There is a progressive increase in mean apnea lengths at each new age group with a simultaneous decline in breathing rates, indicative of greater efficiency at utilizing the air breathed. These mammals have somehow achieved a balance between life on land and life in water. (Supported by NIH-FIC MIRT Grant TW 00033-03)

2:45AM BIO-13 South Florida's Urban Insect Fauna: Barry University as an Example. JASON F. MATE NANKERVIS AND ALLEN F. SANBORN, Barry University, School of Natural and Health Sciences, 11300 N.E. Second Avenue, Miami Shores 33161. A study of the insect biodiversity was carried out on the university grounds. The situation and characteristics of the study site made it a good example for most of South Florida's urban areas. Habitats included extensive turf/garden areas as well as a highly degraded pine scrub plot. Species were classified to the lowest taxonomic level possible. An excess of 325 species representing 18 orders were collected and identified. The greatest numbers of species were collected in the Diptera and Coleoptera. Biodiversity is also assessed indirectly by comparison with well known insect group populations from the region. A special interest is placed upon exotics and their effect on native insects.

3:00PM BIO-14 Presence of the Ophiuroid Primary Circlet as an Indicator of Disturbance. J.M. LIESMAN, Department of Biological Sciences, Florida Institute of Technology, 150 West University Boulevard, Melbourne 32901-6975. The brittlestar *Ophiophragmus filograneus* easily casts off its disc in response to predators, storms, and other disturbance factors. Upon regeneration, the brittlestar is unable to replicate the primary circlet, a cluster of six central disc plates formed early in juvenile development. This study uses the presence and absence of the circlet as an indicator for evaluating the impact of disturbance on populations of *O. filograneus*. Adult brittlestars were sampled at one site by corer and sieve every 3 wk beginning September 1995 and during a year of no recruitment. Brittlestars were sized (aged) by measuring oral-frame diameter and categorized for presence or absence of the primary circlet. Using Kendall's rank correlation, the frequency of brittlestars with the primary circlet was ranked against size of the oral-frame. There was a strong inverse relationship: frequency of the circlet decreased as size increased. The relationship reflects the cumulative impact of disturbance on the population. Further work will examine the relationship in a second year of study, an additional site in the second year, and in a population with successful recruitment from the 1980s.

3:15PM BIO-15 Diet and Feeding Biomechanics of the Sheepshead, *Archosargus probatocephalus*. M. M. CUTWA AND R. G. TURINGAN, Florida Institute of Technology, Melbourne 32901. The sheepshead, *Archosargus probatocephalus*

(Pisces: Sparidae), is commonly found in a variety of habitats including seagrass beds, piers, rocky jetties and offshore reefs. It is a trophic generalist, feeding on a wide variety of prey species such as soft-bodied polychaete prey and hard shelled crabs and molluscs. In this study, the volumetric contribution of prey items consumed by sheepshead in six study sites along the east central coast of Florida was investigated. Field collections were made from November 1995 to October 1996. Intraspecific comparisons revealed that sheepshead consumed significantly different prey organisms (e.g. algae, amphipods, bivalves and crabs) among the variety of habitats examined (Kruskal-Wallis test; $p<0.05$). Dietary differences may be associated with fish size, and temporal and spatial variation in prey availability. The relationship between variation in feeding habit and feeding biomechanics in sheepshead found in different habitats will be discussed.

3:30PM BIO-16 Red-headed Woodpecker (*Melanerpes erythrocephalus*) Nesting at Wekiwa Springs State Park, Florida: A Preliminary Report. M. SHANE BELSON, Department of Biological Sciences, University of Central Florida, Orlando 32816. The Red-headed Woodpecker is typically considered a bird of the sandhills. At Wekiwa Springs State Park, Red-headed Woodpeckers breed in habitat ranging from xeric sandhills to hydric pine flatwoods and bayhead edges. Sixty-two nest snags and the surrounding vegetation were quantitatively measured, as were roost snags of both adults and juveniles. Nests were monitored for double brooding. At least 23 birds were banded and both nest site fidelity and dispersion were observed. The effects of fire on potential nest and roost snags and ways to prevent their destruction were investigated. This research is supported by the Florida Park Service, Florida Ornithological Society, Gopher Tortoise Council, and Citizens for Wekiva Basin GEOpark.

3:45PM BIO-17 Hunting Behavior in the Tarantula Hawk Wasp, *Pepsis thisbe* (Hymenoptera: Pompilidae). F. PUNZO. Dept. of Biology, Univ. of Tampa, 401 W. Kennedy Blvd., Tampa, FL 33606. The ethnogram for hunting behavior in *P. thisbe* is described. Behavioral components of hunting include initial approach and antennation of the host, grooming, paralyzation, lapping (in some cases), oviposition, burial, and closure of the burrow. Female wasps exhibited a bimodal diel activity. The spider is most frequently stung through the intersegmental membrane between the sternum and coxa of the first leg. Whether or not a wasp exhibits lapping behavior is determined by the amount of time spent in flight searching for a host burrow.

4:00PM BIO-18 Taxonomic relationships within the Agkistrodontini. D.S. YORK, SNHS, Barry University, 11300 NE 2nd Avenue, Miami Shores, FL 33161. The Agkistrodontini is a tribe of snakes composed of large head-scaled, rattleless pitvipers. Using a morphology based cladistic analysis, it was determined that the Agkistrodontini is a paraphyletic grouping with a minimum of 5 monophyletic genera. Of particular interest is the placement of the cottonmouth (*Agkistrodon piscivorus*) with the Asian genus *Gloydius*. In addition, the copperhead (*Agkistrodon contortrix*) was determined to be a monotypic genus. This suggests the need for a major nomenclatural revision of the genus *Agkistrodon* as *Agkistrodon contortrix* is the type specimen for the genus and may now be the only valid species for the group.

4:15PM BIO-19 Innervation of the Supranasal Sac in the Puff Adder, Bitis arietans. D. S. YORK (1), T. M. SILVER (1), AND A. A. SMITH (2), (1) School of Health and Natural Sciences, (2) School of Podiatric Medicine, Barry University, 11300 NE 2nd Ave., Miami Shores, FL 33161. The supranasal sac is an invagination of the skin between the supranasal and nasal shields of many true vipers. We have found nerve endings in the supranasal sac of the puff adder, Bitis arietans, that resemble the nerve endings in the pit organ of pit vipers. We suggest that the supranasal sac of true vipers, like the pit organ of pit vipers, is a heat detector. This would explain the known preference of puff adders and Russell's viper for warm prey.

4:30PM BIO-20 Hydrological Effects on Tree Growth Rates and Age Correlations in Wetland Reclamation in North Florida. M. S. BATTS, The Phoenix Environmental Group, Inc., 2916 E. Park Ave., Tallahassee 32301. Successful reclamation of mined lands in North Florida are influenced by many factors. Hydrology and age are two of the most important factors in maximizing growth rates of planted trees and the overall ecological well being of the reclaimed systems. Hydrological fluctuations consistent with rainfall patterns enhance the overall growth rates of planted wetland trees. Planted trees experiencing hydrological cycles consistent with rainfall events displayed the highest growth rates among 18 reclaimed areas. Age of the reclamation system appears to positively influence water quality, vegetation cover, decreased exotic and nuisance vegetation species occurrence, total carbon in the soil, regeneration, and overall habitat value. Using qualitative bioassessment techniques and statistical linear correlations, the assumption that wetland reclamation improves with time is supported.

4:45 PM BIO 21 The MacArthur Agro-ecology Research Center - An Integrated Research Program to Develop Sustainable Cattle Production Systems for Florida. J. C. CAPECE, M. MOZAFFARI AND G. T. BANCROFT. University of Florida. Institute of Food and Agricultural Sciences. Southwest Florida Research and Education Center. P.O. Box 5127. Immokalee. FL.34143-5002.
and Archbold Biological Station, Lake Placid. FL 33852. Rangelands and improved pastures are major components of the central and south Florida's land

use mosaic. Given the importance of these land uses, the University of Florida. South Florida Water Management District and Archbold Biological Station have initiated an integrated research program to develop sustainable cattle management practices. The program, begun in 1990, involves collaboration among scientists from a number of disciplines. This presentation will outline the concept, approach, structure, and achievements of this research program. Also, the design of a new, large-scale field experiment that will investigate the effect of cattle stocking rate on water quality and other ecological indicators will be described. The applicability of this approach to other regional agricultural production systems such as citrus, vegetables, and sugarcane will be discussed.

COMPUTER/MATHEMATICAL SCIENCES

FRIDAY 10:30AM ROOM 211 in Classroom Bldg.
SECTION MEETING: COMPUTER/MATHEMATICAL SCIENCES
Daryl Schrader, St. Petersburg Junior College, Presiding

ENGINEERING SCIENCES

FRIDAY 3:00 PM, ROOM 210 in Classroom Bldg.
Al Hall, City of Tallahassee, Presiding

3:00 PM ENG-1 Recovery of Liquefied Methane and Carbon Dioxide From Landfill Gas. DAVID BRUDERLY, Bruderly Engineering Associates, Inc., 1826 NW 57th Terrace, Gainesville, Florida 32605-3357. Landfills are the least-cost method of solid waste disposal in Florida. Unfortunately, organic material deposited in landfills will decompose through biological processes and form a complex mixture of gases comprising methane, carbon dioxide, oxygen, nitrogen and trace amounts of a large number of organic and inorganic compounds. These gases diffuse through the waste and cover system, and escape to the atmosphere. The reactive organic gases are major sources of air pollution, and the methane is a potent greenhouse gas. Estimates of the pollution produced in Florida by this method are presented, as well as voluntary and regulatory methods of control which are being implemented. The paper also discusses the available technology and economics for recovery, clean up and conversion of landfill gas to liquefied methane and carbon dioxide, and describes how public officials and landfill managers may design a program for capture and use of landfill gas in productive applications.

3:15 PM ENG-2 A Simulation of the Manufacturing Process of a Cast Steel Roll for a Hot Strip Mill. S. SODRE daSILVA and F. B. BUONI, Florida Institute of Technology, 150 West University Boulevard, Melbourne, Florida 32901. The authors describe the development of a simulation model to provide information to forecast a cast steel roll production schedule for a hot strip steel mill.

3:30 PM ENG-3 Job Shop Scheduling With Machine Availability Constraints. Y. C. LI and F. B. BUONI, Florida Institute of Technology, 150 West University Boulevard, Melbourne, Florida 32901. The job shop scheduling problem usually assumes that a machine is always available to the scheduler to schedule the jobs. We discuss the case in which the machine is not always available, due to preventive maintenance, a deterministic process, or breakdown and corrective maintenance, which is a stochastic process. The formulation of the problem is presented.

3:45 PM ENG-4 Continuous Quality Improvement in Engineering Education. G. GARRIDO and F. B. BUONI, Florida Institute of Technology, 150 West University Boulevard, Melbourne, Florida 32901. We address the application of Continuous Quality Improvement (CQI) to engineering education. Deming's 14 points are discussed as they apply to the educational environment in the classroom. We conclude that there is not a single way of making the turnover from the traditional to the new environment in the classroom. However, CQI looks like a safe route that educational institutions may take if quality of learning is to be improved permanently.

4:00 PM ENG-5 The Florida House: A State-of-the-Art Sustainable House. JOHN LAMBIE, The Florida House, Sarasota County Technical Institute, Sarasota, Florida. The Florida House combines energy-efficiency design and amenities with recycled, non-toxic building materials. It provides a model for green residential design in Florida and also acts as a marketing tool for sustainable design-oriented products and materials. The house blends proven climatic design features, such as building orientation, with modern technology, such as the super-efficient air conditioning system. Many of the building components for the home are made from non-toxic, recycled products, including the carpet, floors, decking, posts, railings, and doors. Some other examples of sustainable design features include water-saving devices such as cisterns which collect rainwater for the low-flush toilets, and smart faucets which automatically shut off when not being used.

FRIDAY 5:00 PM, ROOM 210 in Classroom Bldg.
SECTION MEETING: ENGINEERING SCIENCES

Al Hall, City of Tallahassee, Presiding

ENVIRONMENTAL CHEMISTRY AND CHEMICAL SCIENCE

Friday 8:00 AM, ROOM 202 in Classroom Bldg.
SESSION A
Barbara Martin, University of South Florida, Presiding

8:00AM ENV-1 Useful Applications of Diamagnetism, ROBERT F. BENSON, BARBARA B. MARTIN, DEAN F. MARTIN, Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620 AND ROLAND K. CARPENTER, AquaMagnetics® International, Inc. 915-B Harbor Lake Drive, Safety Harbor, FL 34695. Diamagnetism is useful for treatment of water for scale prevention. The approach has been used for a century, but it still has controversial aspects. We believe that a model based upon the increase in entropy of a system in the presence of a magnetic field is useful for understanding the process. The Van Vleck equation will be described as a useful tool, and examples of the utility of diamagnetism will be provided.

8:15AM ENV-2 The Magnetic Separation of Iron from Phosphate Ore. CHUHUA WANG, EILEEN PEREZ, BARBARA B. MARTIN, ROBERT F. BENSON, AND DEAN F. MARTIN, Institute for Environmental Studies, Department of Chemistry, 4202 East Fowler Avenue, University of South Florida, Tampa, FL 33620. Iron is one of impurities in wet processed phosphoric acid (WPA) and ferric ion is identified as a major sludge-forming impurity in shipping grade of WPA due to its significant contribution to postprecipitation. Magnetic methods were used to remove the paramagnetic material containing iron species from phosphate ore before reaction with sulfuric acid. Aqueous ore suspension with particle size of 18-120 mesh (0.125 - 1 mm diameter) was passed horizontally through a Y-tube, to which was attached on one side two 2000- gauss strength magnets. At optimum conditions, the iron content in ore from magnet side was 9.5% -16.7 % higher than that from the non-magnet side. This magnetic apparatus has the potential for iron removal in phosphate industry without extra energy costs. This research is supported by the Florida Institute of Phosphate Research.

8:30AM ENV-3 Effects of Physical and Chemical Comminution on the Beneficiation of Phosphate Rock, ROBERT F. BENSON AND DEAN F.

MARTIN, Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620. The similar responses of calcium carbonate minerals and phosphate rock to many beneficiation processes have hampered the utilization of many low-grade phosphate rock deposits. Since the comminution of most phosphate rock is carried out in a ball mill, little attention has been given to the potential, for selective size reduction and classification as a means for beneficiation. Results from attrition milling and hydrocyclone classification of low-grade phosphate rock will be presented.

8:45AM ENV-4 Solubilization of Sodium Fluorosilicate Scale Using Diamagnetism, CHUHUA WANG, EILEEN PÉREZ, ROBERT F. BENSON, AND DEAN F. MARTIN, Institute for Environmental Studies, Department of Chemistry, University of South Florida, Tampa, FL 33620-5250. Diamagnetism was used to enhance the solubility of sodium fluorosilicate scale in phosphoric acid. Previous research (Benson et al.1994. J. Environ. Sci. Health, A29: 1553-1564) has indicated the basis of enhanced solubility of particles in the presence of a magnetic field (an enhancement of the entropy of the system). The principle was applied to sodium fluorosilicate in the presence of fields of the order of 1200 gauss, and the solubility in 28% phosphoric acid was consistently enhanced by 50 % at room temperature. Implications of the research, supported by the Florida Institute of Phosphate Research, will be considered.

9:00AM ENV-5 A Preliminary Examination of the Effects of a Magnetic Field on the Viability of Four Algae, BARBARA B. MARTIN, DEAN F. MARTIN, AND LINDA D. BISNAUTH, Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620. The effects of magnetic fields (nominally 1200 gauss, generated by permanent magnets) on the growth of selected model organisms are summarized. For single-celled marine organisms (*Gymnodinium breve* and *Nannochloris oculata*) viability was measured as cell counts as a function of time. For filamentous algae (cyanobacteria), total chlorophyll was used to infer viability. *G. breve* , but not *N. oculata* was adversely affected by a magnetic field during a two-day period. *Lyngbya majuscula* and *Oedegonium foveolatum* were affected by a magnetic field during a two-week period.

9:15AM ENV-6 Investigation of a Freon-Free Nonvolatile Residue Test for Space Flight Hardware. C.A.CLAUSEN, J. GUIDRY, AND C.M.CLAUSEN. Department of Chemistry, University of Central Florida, Orlando,32816. Liquid oxygen is used as the oxidizer for the liquid fuel main engines during the launch of the space shuttle. Any hardware that comes into contact with pure oxygen either during servicing of the shuttle or in the operation of the shuttle must be validated as being free of nonvolatile residue (NVR). This is a safety requirement to prevent spontaneous combustion of carbonaceous NVR if it were to come into contact with pure oxygen. Previous NVR validation testing of space hardware used freon (CFC-113) as the test solvent. Because CFC-113 no longer can be used, a program was conducted to develop a NVR test procedure that uses a safe and environmentally friendly solvent. This paper will describe the work that has been conducted on the use of water as the test solvent. Equilibration of the NVR from the hardware part into the water was found to be facilitated by the use of ultrasonic energy. The wash solution is then tested for the presence of NVR by measuring the total organic carbon concentration (TOC). For the validation of large parts, a procedure was developed for concentrating the NVR prior to TOC analysis.

9:30AM ENV-7 Reductive Dehalogenation of Trichloroethene Using Zero-Valent Iron and UltrasonicEnergy. C.L.GEIGER[1], C.A.CLAUSEN[1], D. REINHART[2], N. RUIZ[2], G. AFIOUNI[1], P. TOY[1], N. LAO[1]. Departments of Chemistry[1] and Environmental Engineering[2], University of Central Florida, Orlando,32816.Because chlorinated solvents are so versatile in their application they have found use throughout our society. This has resulted in a wide spectrum of contamination problems. Because of the limited success in remediating contaminated sites by pump-and-treat techniques, considerable effort is being directed toward the development of in situ treatment methods. The methodology that is being studied is based upon the generation and use of in situ chemically reactive permeable treatment walls for remediation and containment of groundwater plumes contaminated with chlorinated solvents. The rate of degradation of TCE has been increased by using reactive metal (i.e. iron) of high surface area. However, because this process reduces the iron, it is inherent in the system that corrosion of the iron surface occurs. As TCE is converted to ethane, the pH of the system increases causing precipitates to form on the iron surface and slowing the rate of TCE removal. Preliminary work suggests that periodic in situ treatment of the reactive wall with ultrasound can enhance and restore the degradation rate of the active metal.

9:45AM ENV-8 Establishing a Laboratory for Physical Environmental Sciences at Valdosta State University. THOMAS J. MANNING, Dept. of Chem., Valdosta St. Univ., Valdosta, *Ga. 31698* Valdosta State University, located in Lowdnes County (GA), on the Florida border, is establishing a laboratory for physical environmental sciences that will interact with the states pulp and paper industry. Equipment committed to the facility include a ICP-AES, ICP-MS, FFFF-MALLS system, particle size analyzer, carbon analyzer, UV/VIS spectrometer, and a 300 MHZ NMR. The facility, which will come on line in July 1997, will work with industry to help them solve problems. The talk will discuss details of this facility.

10:00AM BREAK

10:15AM ENV-9 Physiochemical Studies on the Biliprotein Pigments in Representatives of Two orders of Pelagic Cnidarians: *Physalia physalis and Velella velella.* CLIFF I. ROSS, J. WILLIAM LOUDA, AND FRANK MARI. Department of Chemistry and Biochemistry, Florida Atlantic University, 777 Glades Rd. Boca Raton, Fl. 33431. *Physalia physalis* (Portuguese man-of-war) and the *Velella velella* (by-the-wind-sailor) are brightly pigmented members of the pleustonic community of tropical and subtropical waters (Zaitsev, 1964; David, 1967) whose range occasionally extend into temperate areas. The toxic properties of the nematocysts of these organisms have been previously described (Lane,1960), but the biochemical nature of their characteristic pigmentation has not been extensively investigated (Ball & Cooper,1947 and Herring, 1970). A more detailed study has been carried out in order to determine the relationship between the biochemistry and function of the pigments of *Physalia* and *Velella.* Previous work has indicated that the coloration of *Physalia* is due the presence of biliproteins. Bilins are tetrapyrrole chromophores found covalently attached to biliproteins that are responsible for color. A biliprotein mixture has been isolated from *Physalia* and *Velella* collected off the coast of Boca Raton, Florida. The isolation procedure included ammonium sulfate precipitation, gel filtration chromatography as well as SDS and IEF electrophoresis. Further separation was conducted via HPLC. Final analysis of the biliproteins and their prosthetic groups was carried out by NMR spectroscopy, UV-VIS, and Fluorescence spectroscopy. The results from the isolation and characterization procedure and a comparative analysis of the pigmented proteins found in these organisms will be discussed.

10:30AM ENV-10 Examination of VP1 of Polyomavirus: Introduction and NMR Studies. S. M. STANCZYK, R. H. MEYERS, J. K. NELSON, AND D. M. PRATHER, Eckerd College, St. Petersburg, FL 33711. The polyomavirus consists of a super-coiled circular DNA molecule inside a protein shell. This shell is made up of three viral proteins, with one (VP1) Comprising 75% of it. Five VP1 molecules associate to form a "capsomere," 72 of which associate into a "capsid" making up this shell when Ca2+ is added. Self-assembly properties of VP1 were studied in both ground-based trials and in conditions of microgravity. In the latter, the capside shell would not form, possibly due to protein unfolding. This unfolding may have altered the Ca2+ binding portion, or "domain," of VP1 so that proper assemby is not possible. The Ca2+ binding domain of VP1 is made up of a sequence of 12 amino acids, and this sequence resembles those in Ca2+ binding domains of other proteins. This peptide has been synthesized, purified, and has undergone NMR analysis. Two dimensional studies involving the COSY, NOESY, ROESY, and TOCSY pulse sequences have been done. The data obtained thus far will be presented. (Funding from NASA-JOVE).

10:45AM ENV-11 Analytical Method Validation for the Separation of Testosterone and Related Steroids by Micellar Electrokinetic Capillary Chromatography using Sensitized Terbium Fluorescence Detection. R. E. NEGRON AND J. M. ROBERT, Department of Chemistry, CHE 305, University of South Florida, 4202 E. Fowler Ave., Tampa, FL 33620-5250. An analytical method validation was performed for an MECC steroid analysis developed previously in our laboratory. Steroid sample mixtures containing corticosterone, progesterone, testosterone, testosterone acetate, and methyl testosterone were prepared at 30% to 150% of a target concentration (6.5×10^{-5} M each). Steroid migration times ranged from 15 to 22 minutes, and migration time reproducibilities varied from 0 to 5 % RSD. Peak areas varied linearly with concentration over the 90% to 150% range; however, below 90% of the target concentration deviations from linearity were observed. Results will be discussed and additional data presented for samples prepared in a mock biomatrix.

11:00AM ENV-12 "Lactam -inverted" Analogues of the Penem and Clavulanic Acid Antibiotics. M. I. KONAKLIEVA, H. SHI, AND EDWARD TUROS, Dept. Of Chemistry, Univ. Of South Florida, Tampa, FL 33620. Our studies on the synthesis of novel β-lactam ring systems related to the penem and clavulanic acid families of antibiotics will be described. The bicyclic core of the analogues can be easily constructed by a [2 + 2]-cycloaddition reaction between an α, β - unsaturated imine and an acid chloride followed by a regiospecific halocyclization process, and further derivatized using palladium-catalyzed transformations of a vinyl halide.

11:15AM ENV-13 Cloud-point Extraction of Chromium (III) Ion as Neutral Complexes From Wastewater. CHUHUA WANG AND DEAN F. MARTIN, Institute for Environmental Studies, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620. A surfactant- mediated extraction, cloud-point extraction, was used to replace the conventional liquid-liquid extraction for chromium(III) ion from aqueous solutions. 8-hydroxy-quinoline, 2-methyl, 8-hydroxy-quinoline, 5-Cl- 8-hydroxyquinoline, and Kelex 100 (C_{11}-substituted 8-hydroxy-quinoline) were used as ligands to form chromium complexs. The investigation used pH = 5.5 buffer solutions and initial chromium (III) concentration was 27- 105 ppm. Ligand molar concentration should be more than 3 times as much as that of chromium(III) ion. For small ligands, the reaction reached equilibrium within 2 hours, and the chromium concentration was reduced to less than 1 ppm. Kelex 100 reacted with chromium(III) ion very slowly because of the ligand's hydrophobic and steric hindrance. Since hydrated chromium ion, $[Cr(H_20)_6]^{3+}$, is inert for ligand exchange, the choice of ligands for chromium complex formation is limited.

11:30AM ENV-14 Mechanism of Phosphonic Acid Adsorption Onto Aluminum Oxide. WENDY M. FOSS AND JEROME E. HAKY, Department of Chemistry and Biochemistry, Florida Atlantic University, Boca Raton 33431. Phosphates and phosphonates strongly interact with metal oxides, such as those found in the sediments of freshwater lakes and streams. We report here the results of a laboratory study of the adsorption of phenylphosphonic acid onto the surface of aluminum oxide (alumina) from aqueous solution. It was found that an initial monolayer of the phosphonic acid is strongly bonded to the alumina surface, while additional layers are more weakly adsorbed. Maximum monolayer coverage occurs in the pH range of 3-4, which corresponds to conditions favoring formation of the singly charged phenylphosphonate ion, $C_6H_5PO_3H^-$. These results are consistent with a condensation reaction between the phosphonic acid and surface hydroxyl groups on the alumina. The process is enhanced by electrostatic attraction of negatively-charged phosphonate ions to a positively-charged alumina surface.

11:45AM ROOM 202 in Classroom Bldg.
SECTION MEETING
Barbara Martin, University of South Florida, Presiding

NOON-12:30 PM IN REGISTRATION AREA ENV-POSTER Synthetic and Computational Studies of Unusual "Lactam-inverted" Beta-Lactams. EDWARD TUROS (1), M. KONAKLIEVA (1), H. SHI (1), AND F. J. GONZALEZ (2). (1) Dept. Of Chemistry, Univ. o f South Florida, Tampa, FL 33620, (2) Dept. of Organic and Inorgani Chemistry, Univ. of Oviedo, Oviedo, Spain.

Friday, 2:00 PM, ROOM 202 in Classroom Bldg.
SESSION B
Dean Martin, University of South Florida, Presiding

2:00PM ENV-15 The Invasion of Carrotwood (*Cupaniopsis anacardioides):* A Study Comparing the Impact of an Exotic Species on Two Islands in Sarasota, Florida. L. A. DOWNEY. New College of USF, 5700 N. Tamiami Trail, Sarasota 34243. The Carrotwood tree, a native of Australia, is commonly planted for landscaping purposes in southern Florida. After escaping cultivation in the 1980s, it quickly established itself on mangrove and spoil islands where it thrives under the shade of Australian Pines and among coastal and inland mangroves. The species has recently been added to a Sarasota County ordinance (along with Australian Pine, Brazilian Pepper and Maleluca trees), banning its future sale, transport and propagation. This is the first step in controlling Carrotwood growth. However, a lack of research into the species, particularly in southern Florida, limits the action county officials can take. Therefore, my thesis will focus on baseline scientific experiments that determine Carrotwood density as well as elevation and soil requirements. Two islands will be studied: John Mac Donald island in Robert's Bay- formed completely from spoil; and Otter Key in Sarasota Bay- a natural island onto which spoil was dumped in the 1920s. This data will be used to compare the impact of the exotic species on two islands of different historical and vegetative origins and to develop a plan to eradicate and control the species.

2:15PM ENV-16 Evaluation of Allelopathic Materials Produced by *Nannochloris Oculata*. E. PEREZ, D. F. MARTIN, AND W. SAWYERS, Institute of Environmental Studies, Department of Chemistry, University of South Florida, 4202 E. Fowler Ave., Tampa, FL 33620. It has been found that the green alga, *N. oculata*, is allelopathic to Florida's red tide dinoflagellate, *Gymnodinium_breve* . Two of the *N. oculata* toxins have been identified by GC-MS as methyl stearate and methyl palmitate and are being characterized. This on-going research is concerned with evaluating the total effect of these toxins on *G. breve* , in addition to the factors affecting its growth, biological activity and action mode against *G. breve*.

2:30PM ENV-17 Relative Concentrations of Allelopathic Materials in Cattail Plants (*Typha dominguensis*). MARIA T. GALLARDO AND DEAN F. MARTIN. Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4020 E. Fowler Ave., Tampa, FL 33620. 2-chlorophenol and salicylaldehyde are thought to be among the chemical species responsible for the allelopathic behavior of cattails. This research deals with the determination of the concentration and distribution of this compounds in the cattail plants and its release in the surrounding waters in an effort to characterize the observed toxic effect of the cattails over other plant species.

2:45PM ENV-18 Isolation of Allelopathic Substances from Cattails, Typha domingensis, from Hillsborough County. VICKI PRINDLE, WILLIAM G. SAWYERS, BARBARA B. MARTIN, AND DEAN F. MARTIN, Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620. Cattails from a USF campus pond had been identified as containing allelopathic compounds [Prindle and

Martin, *Florida Scient*. 59:155-162] on the basis of testing aqueous isolates against lettuce seeds. The extracts were passed through an EXTRA-SEP column , a commercial C-8 chromatography column, then extracted with methanol. The extracts were subject to analysis with GC-MS using a H.P. model 5890 series II gas chromatograph and a computerized H.P. model 5972 mass selective detector. Two known substances, 2-chlorophenol and salicylaldehyde, were identified, based upon comparison with literature spectra. Authentic samples of both were tested against lettuce seeds and found to be allelopathic.

3:00PM ENV-19 The Impact of Tobacco on Nitrate. ROBERT S. BRAMAN (1), MARGARET FARAGO (2) AND IAN THORNTON (2), (1) Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620 (2) Centre for Environmental Technology, Imperial College of Science, Technology, and Medicine, Prince Consort Road, London SW7 2BP. The nitrate content of tobacco produces nitric oxide in primary tobacco smoke. It has bene demonstrated that nitric oxide produces nitrosoamines when reacting with amino acids having secondary amine nitrogens. This may account for the increased mortality rate among smokers. Analyses of tobacco products for nitrate by country of origin of the tobacco products is strongly correlated with the mortality rate for smokers.

3:15PM ENV-20 The Recycling Index Revisited. BARBARA B. MARTIN AND DEAN F. MARTIN, Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620. The Recycling Index was defined previously [Martin and Martin, Florida Scient. 59:65-73] as the ratio of the recycling percentage to the target percentage (30% for Florida,). The Recycling Percentage was defined as being equal to 100R/(R +L + C), where R is the total mass of solid waste recycled, L the amount placed in landfills, and C the mass of solid waste combusted. Affected counties in Florida met the targets set by in the 1988 Florida Solid Waste Act. Now it seems pertinent to review the current status and revisit the question of the usefulness and problems of recycling. For example, how much solid waste might we expect to be produced, and how much land might be consumed for landfills? Is recycling cost-effective? Does recycling contribute to air pollution?

3:30PM ENV-21 Patterns of Water Chemistry and Fish Occurrence in Wetlands of Hydric Pine Flatwoods in Southwestern Florida. W. A. DUNSON (1), C. P. PARADISE (1), AND R. VAN FLEET (2), (1) Dept. of Biology, Penn. State Univ., University Park 16802, (2) Sarasota Cty. Natural Resources, Sarasota,34232. We measured water specific conductance, cations [Na,K,Ca,Mg], and fish species occurrence in wetlands of the Carlton Reserve and Myakka Flatwoods State Forest. Wetlands varied from 20 to >500 µS/cm, yet they appeared to be a single water type. [Na], [Ca], and [Mg] were strongly positively correlated, but not [K]. Fish species varied with water chemistry and wetland origin (natural vs constructed). We conclude that the softest wetlands are the most isolated; thus monitoring of specific conductance would be a simple way of determining anthropogenic changes in wetland hydrology.

3:45PM ENV-22 Areal Estimates of Sediment Contamination by Trace Metals in Tampa Bay, 1993-1995. S.A. GRABE, T.C. CARDINALE, AND S. PEREZ. Environmental Protection Commission of Hillsborough County. 1900 9th Ave. Tampa, FL 33605. Sediment contamination by trace metals (Ag, As, Cd, Cr, Cu, Ni, Pb, and Zn) in four segments of Tampa Bay (Old, Hillsborough, Middle, and Lower Tampa Bay) was estimated an an areal basis. Sampling design was the random, probability-based approach used by the USEPA's "EMAP" program. Contamination was defined by the Threshold Effects (TEL) and Predicted Effects (PEL) levels developed for Florida coastal waters. A total of 234 samples were collected during September-October 1993-1995. Hillsborough Bay, the most industrialized segment, showed greatest extents of contamination: more than 15 km^2 of Hillsborough Bay bottom was estimated have Cd, Cu, Ni, and Cr concentration in excess of the TEL. The extent of contamination, both in area and percentage of the segment, was considerably lower in the other bay segments.

4:00PM ENV-23 Natural Fertilization: Is the Clean Air Act Going Too Far? JAY W. PALMER, Institute for Environmental Studies, Department of Chemistry, University of South Florida, 4202 E. Fowler Ave., CHE 305, Tampa 33620-5250. The EPA is proposing tough new rules to fight smog. These new rules could significantly improve the health of millions of Americans at a cost of billions of dollars. However, in semi-tropical areas such as Florida, there is concern that these rules might reduce the natural fertilization of wetlands and forested areas, and also increase the rate of global warming. An assessment will be made of these concerns.

4:15PM ENV-24 The Extinction Coefficient for Photosynthetically Active Radiation (PAR) in Coastal Waters. G. A. BLANCHARD AND R. C. BROWN, Manatee County Environmental Management Dept., P.O. Box 1000, Bradenton 34206-1000. How the extinction coefficient of PAR (k) varies with respect to other water quality variables became an important issue during the development of management actions for the Tampa Bay National Estuary Program. A procedure was developed to determine a spatially consistent *k* value from PAR measurements at two, 2-Pi underwater quantum sensors with 0.5m vertical separation that measured PAR at depths of 1.0m and 1.5m. These *k* measurements and covariate data on turbidity, color, and chlorophyll from the Manatee County Environmental Management Dept.'s regional water quality monitoring program are examined for relationships between water column transparency and water quality.

4:30PM ENV-25 Characterization of Productivity and Photosynthetic Taxa Using Chlorophyll and Carotenoid Biomarker Studies on the Waters and Sediments of Florida Bay. J.W.LOUDA(1), J.W.LOITZ(1), E.W.BAKER(1), and D. T. RUDNICK(2). (1) Florida Atlantic University, Boca Raton, Florida, 33431, (2) South Florida Water Management District, West Palm Beach, Florida, 33416. Florida Bay has experienced seagrass and sponge die-offs and sporadic algal blooms. The present study targets the chlorophylls and carotenoids as biomarkers with which to study the crude taxonomic (*i.e.* Divisional) makeup of present and past algal and phototrophic bacterial populations. Further, relationships of pigment abundances in the sediments, as related to bulk organic carbon, are being traced in efforts to unravel the history of Florida bay algal blooms, hopefully extending that history to the pre-Man era. The pigments of the main microalgae in the Florida Bay blooms have been typed and studies reveal their presence in the waters and sediments of the bay. This includes: zeaxanthin and β-carotene in Synechococcus elongatus; chlorophylls-*c1/-c2*, fucoxanthin and 2 characteristic carotenols in Cyclotella choctawatcheeana; and myxoxanthophyll, zeaxanthin, and echinenone in an unidentified spherical picoplankter. All species also contained chlorophyll-*a*. Studies on the unique lime muds of Florida Bay continue at this writing.

4:45PM ENV-26 Senescence, Death and Early Diagenetic Alterations of Chlorophyll-*a* in Pure Algal Cultures and Recent Sedimentary Environments. J. LIE, J. ZHENG, E.W. BAKER and J.W.LOUDA. Organic Geochemistry Group, Department of Chemistry and Biochemistry, Florida Atlantic University, Boca Raton, Florida 33431. The transformations of chlorophylls, especially chlorophyll-*a*, were investigated using reverse-phase ion-pairing high-performance liquid-chromatography coupled to full spectral acquisition via photodiode array detection. RP-HPLC/PDA techniques were standardized against a wide variety of authentic chlorophylls, chlorophyll derivatives, and carotenoids. Unispecific algal, cyanobacterial and photosynthetic bacterial cultures were subdivided, purged with nitrogen, and incubated in the dark and at either at room(24°C) or refrigerator(4°C) temperature for various lengths of time(1-4 weeks, several months, 1-2 years). Most of the studies to date cover the qualitative changes of chlorophyll-a, including species specificity in the formation of the various pheopigments. Recent studies include the quantitation of overall pigment loss, to either identifiable pheopigments or to unknown small non-pigment compounds.

GEOLOGICAL AND HYDROLOGICAL SCIENCES

FRIDAY 2:00 PM, ROOM 109 in Classroom Bldg.
Jon Arthur, Florida Geological Survey, Presiding

2:00PM GHY-1 Subsurface geological mapping in southwest Florida - a GIS approach, J.D. ARTHUR (1) AND M. KELLEY (2), (1) Florida Geological Survey, 903 W. Tennessee St., Tallahassee, Fl 32304, (2) Southwest Florida Water Management District, 2379 Broad St., Brooksville, Fl 33512. The Florida Geological Survey and the Southwest Florida Water Management District have entered into a cooperative effort to generate detailed subsurface geological maps of the southwest Florida region. Over a three-year period, structure contour and isopach maps will be constructed for all regionally identifiable units above and including the top of the Eocene Avon Park Limestone (lithostratigraphic) and the middle confining unit of the Floridan aquifer system (hydrostratigraphic). Control points will be selected utilizing a recently developed GIS database that includes more than 4000 boreholes in the region for which samples (cores or cuttings) and/or geophysical logs exist. A control-point density of one borehole per ten square miles is targeted. Map generation and contouring will be completed using GIS software. Final editing will include structural and stratigraphic interpretation. These maps will be useful for ecosystem management, resource permitting, rules enforcement, conceptual frameworks for ground-water flow models, and baseline geologic and hydrogeologic research.

2:15PM GHY-2 Deep Well Injection in the Charlotte Harbor Vicinity. J. L. HABERFELD, Florida Dept. of Environmental Protection, 2600 Blair Stone Rd., Tallahassee, 32399. Deep injection wells have been used to dispose of wastewater in Florida since 1963, and in the Charlotte Harbor area since 1986. Six injection sites with a total of seven wells dispose of approximately 4.5 million gallons of wastewater per day. The wells are located at municipal and private utility sites on all sides of the harbor. Wells at four of the sites dispose of secondary treated municipal wastewater; one site disposes of desalination reject water; and one site disposes of treated landfill leachate. The vast majority of injected water (97%) is municipal effluent. Depths of injection zones range from 1100 to 3200 feet. The injection zones are highly permeable, fractured dolomite of Eocene age which contain saline water. Changes in lithology result in the permeable intervals being encountered deeper toward the south. The injection zones are overlain by less permeable limestone and shale. These confining intervals restrict the wastewater to the injection zones thereby protecting the overlying aquifers. Water quality data from wells completed in overlying aquifers demonstrates the injection process is not affecting usable ground water.

2:30PM GHY-3 A High-resolution Study of Karst Topography in Central Florida with Applications to Sinkhole Hazard. D. WHITMAN (1), AND T. L. GUBBELS (2), (1) Dept. of Geology, Florida International University, Miami, 33199, (2) Hughes Information Technology Systems, Landover, MD 20774. We are utilizing modern techniques of digital elevation model (DEM) construction and analysis to study karst processes and sinkhole hazard at scales ranging from tens of centimeters to hundreds of kilometers. The investigation focuses on a region of relatively high topographic relief to the west of Orlando. Preliminary results include construction of a 30-m-resolution DEM constructed from 5' topographic contours which spans a 30'x30' area centered on Lake Apopka. This data along with coincident geologic and hydrologic data, aerial photography, and satellite imagery are being utilized to characterize spatial features and their relationships to spatial/temporal patterns of sinkhole occurrence. In selected portions of the study area, an airborne pulsed laser topographic mapper was deployed in November, 1995. This data which has a vertical accuracy of < 1 m and a horizontal resolution of ~ 2 m will be used to produce very high resolution DEMs in selected areas in order to characterize topography at the finest horizontal scales and for the detection of subtle topographic features related to incipient sinkhole formation.

2:45PM GHY-4 Modeling The Hydrodynamics of Karstic Landlocked Lakes. W. L. EVANS III, Florida Department of Environmental Protection, 2600 Blairstone Road, Tallahassee, FL 32399-2400. Fluctuations in lake levels are known to involve seepage beneath lakes. Lake level decline due to seepage is governed by the effective-head gradient acting across the lake bottom, the hydraulic conductivity of the lake bottom, and the hypsometry of the lake basin. The conductivity and hypsometry are constant for geologically short periods of time, and the head gradient is determined by the lake level. Thus, as a lake level declines, the hydraulic gradient decreases, and the rate at which the level of a lake declines is a function of its level. After accounting for the effects of potential evapotranspiration (PET) and delayed recharge, fluctuations in lake level should resemble a series of exponential decay curves whose parameters reflect basin hypsometry and lake-bottom conductivity. Hydraulic conductivity estimates of lake sediment cores were used to estimate seepage through the lake bottom by utilizing a weighted average approach. As lake levels and lake area fluctuated, the equivalent areal hydraulic conductivity (K_A) varied. A second order polynomial was derived to describe the variation in K_A. From the K_A estimates, seepage flow ($L^3 t^{-1}$), and seepage ($L t^{-1}$) through the lake bottom were modeled. Seepage flow, as a primary function of declining lake level, behaved exponentially. Seepage, as a function of seepage flow and lake hypsometry declined linearly with declining lake level. Lake PET was estimated from the modeled seepage and is approximately double that of the pan evapotranspiration data which suggests that the modeled PET is more representative of lake transpiration. This model was applied to Lake Jackson near Tallahassee, Florida, a closed lake system formed by karstic processes.

3:00PM GHY-5 Inferred Rapid Sea-level Changes at the Close of the Last Interglacial: Evidence from the House of Refuge in Martin County. D. W. LOVEJOY, Palm Beach Atlantic College, P. O. Box 24708, West Palm Beach 33416. Coastal notches are cut at or just below low-tide level into indurated limestone by the boring and browsing activities of various organisms in concert with physical conditions such as wave erosion and low tidal range. Along the Florida east coast notched outcrops of the Anastasia Formation, a Late Pleistocene coquinoid limestone, appear from St. Augustine south to Ormond Beach, from Cocoa south to Eau Gallie, and from Stuart south to Boca Raton. At the House of Refuge, which is located near the south end of Hutchinson Island in Martin County, an inferred fossil notch appears at a height of +6m. To incise such a narrow notch, and preserve its original profile, would require a rapid but brief rise in sea-level to notch position, followed by a short crest, and a subsequent fall in sea-level rapid enough to leave the notch profile intact. Cutting of the notch presumably took place during the last interglacial stage.

3:15PM GHY-6 Steinhatchee River Estuary, Taylor and Dixie Counties: a comparison of two sediment digestion methods for normalization of trace metal concentration data. C. A. TRIMBLE (1), J F. DONOGHUE (2), P.C. RAGLAND (2), R. HOENSTINE (1), (1) Florida Geological Survey, 903 W. Tennessee St., Tallahassee 32304, (2) Dept. of Geology, FSU, Tallahassee 32306. The Steinhatchee River is a small relatively pristine bay located on the northwest Florida Gulf of Mexico coast. A baseline study was completed to establish existing conditions in this relatively remote site. Samples collected from 31 locations, representing 4 sedimentary environments, were analyzed for major and trace element content (ICP-AES), texture, cation exchange capacity and total organic matter. Samples were normalized to aluminum concentration, total percent organic matter, cation exchange capacity, and total percent fines (<63mm). Normalization assumes a linear relationship between a naturally occurring metal concentration and a geochemical or sedimentological characteristic. Two ICP extraction methods were evaluated: partial, aqua regia digestion and total, hydrofluoric acid digestion. In most cases data correlations from the aqua regia digestion were as good, or better than those of the hydrofluoric acid digeation method. It was found that aqua regia digestion can be a valuable tool for researchers, particulary when making preliminary studies within a single watershed. This method can be used to located areas for more intensive studies where HF digestion is preferred.

3:30PM GHY-7 Earth science education and environmental stewardship - a video entitled: "*Florida's Geology Unearthed*," J.D. ARTHUR, Florida Geological Survey, 903 W. Tennessee St., Tallahassee, Fl 32304. An understanding of Florida's solid earth, such as aquifers, geologic history and framework, energy and mineral resources, and geologic processes and hazards is essential toward effective, holistic environmental education. However, a very limited number of Florida-specific earth-science education materials exist. To address this concern, a video entitled *Florida's Geology Unearthed* has been produced, along with an accompanying Educator's Guide. The 60 minute classroom video uses a contemporary videographic approach intended for the target 8th- and 9th-grade student audience. A broadcast version for general public education is also available. Goals and objectives of the video include: 1) demonstrate why geology is important regarding infrastructure demands due to Florida's population growth; 2) describe Florida's unique geologic history, how it relates to geologic processes and hazards, and how it has shaped the land surface of present-day Florida; 3) establish the importance of geology to the understanding of Florida's ecosystems; 4) compliment existing education *Sunshine State Standards*; and 5) instill personal awareness and responsibility for Florida's renewable and non-renewable solid-earth resources. An advisory committee of local environmental educators contributed to improving effectiveness of the video in the classroom. A second advisory committee consisting of licensed professional geologists contributed toward technical accuracy.

3:45PM Video, "Florida's Geology Unearthed," J. D. Arthur, Florida Geological Survey, 903 W. Tennessee St., Tallahassee, Fl 32304. Presentation of the video referenced in the previous paper.

4:45 PM, ROOM 109 in Classroom Bldg.
SECTION MEETING: GEOLOGICAL AND HYDROLOGICAL SCIENCES
Jon Arthur, Florida Geological Survey, Presiding

MEDICAL SCIENCES

FRIDAY 11:00 AM, ROOM 211 in Classroom Bldg.
SECTION MEETING: MEDICAL SCIENCES
Alan Smith, Barry University, Presiding

PHYSICAL AND SPACE SCIENCES

FRIDAY, 8:30 AM, ROOM 204 in Classroom Bldg.
Mark Moldwin, Florida Institute of Technology, Presiding

8:30AM PSS-1 Determination of 3-dimensional Positions of Lightning VHF Pulses Using a Modified LDAR System. B. GOODE, AND M. B. MOLDWIN, Dept. of Physics and Space Sciences, Florida Institute of Technology, Melbourne, FL 32901. A study was conducted on data taken from a winter storm over KSC using a modified version of the Lightning Detection and Ranging (LDAR) system. This system allowed a user to find up to 12 spatially separate sources in one 200 microsecond record. The distribution of source altitudes for our study showed two peaks at five and 10 km. The pulses studied here had rise times of less than one micros., and then fell of to a shouldeer of half the intensity. The total signal length was about three micros. The velocity distribution was from 5 x 106 to 2 x 108 m/s with a peak around 107 m/s. This peak shape, duration, and velocities matched the description of the characteristics of pulses that had been identified with recoil streamers in earlier studies. A plate antenna was used to measure the time change of the electric field. 95.1% of events identified as recoil streamers had associated E field changes, many with large scale changes, indicating an association between recoil streamers and K changes.

8:45AM PSS-2 Ship Propulsion by Wind and Water Turbines. J. NORWOOD, JR., Department of Natural Sciences, University of North Florida, Jacksonville 32224. Wind and water turbine propulsion for ships offers the theoretical possibility to sail directly into the wind, and to sail downwind at speeds greater than wind speed. Force and power equations are derived for generic mills and propellers. These are used to analyze four different modes of propulsion for ships and yachts with a range of realistic hull resistances and parasitic air drags. The ratio of ship speed to true wind speed is calculated for all course angles for each of the four propulsion modes along with the optimized propeller and mill pitch parameters. The conditions under which sailing directly to windward and sailing downwind faster than the wind are possible is clearly delineated.

9:00AM PSS-3 Surface and Bulk Electronic States of a Metallic Solid.* L.R. MASLIAH, Department of Physics, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431. Many physical properties of the surface of a metallic solid differ from those in its bulk region. Examples include differences in electronic structure, the arrangement of atoms and in the case of alloys, the relative amounts of each species. This paper focuses on an analysis of differences in the electronic structures of the surface and bulk regions of copper and copper-gold alloys. We will demonstrate how both the total energy and the electron core level energies of an isolated copper atom differ from those of a copper atom inside a solid. Using a first-principles approach, we will compare calculated core-level energies of copper atoms in the bulk with those of atoms in the first few layers at the surface. We will show how the electronic states at the surface of a copper-gold alloy differ when a single species is present from thehere both species are present.

* Supported by the NSF (DMR-9500654) and NATO

9:15AM PSS-4 Electrodeposited CdS Thin Film Solar Cell Windows. H. FORSELL, J. G. MANTOVANI, R. P. RAFFAELLE, Florida Institute of Technology , Dept. Physics and Space Sciences, O. MELENDEZ AND J. HURLEY, NASA-Kennedy Space Center, Materials Science Division. We have been investigating the electrochemical deposition of semiconducting cadmium sulfide (CdS). CdS is used as a window material in $CuInSe_2$ (CIS) thin film photovoltaic solar cells. We have demonstrated the ability to potentiostatically deposit stoichiometrically correct thin films of CdS from a single plating bath at room temperature. It has been shown that, by the fabrication technique used, it is possible to vary the Cd to S ratio for optimal electrical characteristics. This has been illustrated by periodically varying the Cd to S ratio in a multilayer structure. We have used x-ray diffraction (XRD), scanning electron microscopy (SEM), and x-ray photoelectron spectroscopy (XPS) to characterize our CdS thin films. We will present estimates of the optical bandgaps of our CdS films as determined by room temperature optical absorption measurements. Current *versus* voltage behavior will be presented for various heterojunctions involving our electrodeposited CdS thin films.

9:30AM PSS-5 Electrodeposited $CuInSe_2$ Thin FilmSolar Cell Materials. D. PALACIOS, P. KALMANSON, H. FORSELL, J. G MANTOVANI, R. P. RAFFAELLE, Florida Institute of Technology, Dept. of Physics and Space Sciences, O. MELENDEZ AND J. HURLEY, NASA-Kennedy Space Center, Materials Science Division. We have been investigating the electrochemical deposition of semiconducting $CuInSe_2$ (CIS) thin films. CIS is a leading candidate for polycrystalline thin films photovoltaic solar cells due to its favorable optical absorption and electrical characteristics. We have demonstrated the ability to potentiostatically deposit both p and n type materials from the same plating bath by varying the deposition potential. We have used x-ray diffraction (XRD), energy dispersive spectroscopy (EDS), scanning electron microscopy (SEM), and x-ray photoelectron spectroscopy (XPS) to characterize our CIS thin films. Current *versus* voltage behavior will be presented for p-n junctions and various heterojunctions involving our electrodeposited CIS thin films.

9:45AM PSS-6 Weight of a Charged Parallel Plate Capacitor. K. RAYMOND, K. THOMPSON, AND H. HICKMAN, Hillsborough Community College, P. O. Box 30030, Tampa, Fl, 33630. General relativity predicts that a stationary rod placed parallel to a gravitational field will experience length contraction, while a stationary rod placed perpendicular to the same field will not. If this prediction is true, then a charged parallel plate capacitor should contain less electric energy when its plates are oriented perpendicular to the field than it contains when its plates are oriented parallel to the field. Einstein's famous $E = mc_2$ allows an "equivalent" mass to be associated with any amount of energy. If that equation can be applied to electrical energy, then our capacitor should contain the least amount of mass when its plates are oriented perpendicular to the field. A charged parallel plate capacitor then, should weight less when its plates are oriented perpendicular to a gravitational field than it weights when its plates are oriented parallel to the same field.

10:00 AM BREAK

10:15AM PSS-7 A Single Pulse Solution of the Wave Equation. T. NGUYEN, L. NGO, AND H. HICKMAN, Hillsborough Community College, P. O. Box 30030, Tampa, Fl 33630. The most frequently encountered solution to d'Alembert's wave equation is a mathematical description of the form $f(x, t) = A \sin (kx-\omega t)$. This expression describes a sine wave moving to the right with velocity $v = \omega/k$ when t is greater than zero. Unfortunately, the wave already stretches from $x = -\infty$ to $x = +\infty$ when $t = 0$. (Real physical waves do not begin by filling all of space.) Multiplication of $f(x, t)$ by a composite Heavyside unit step results in $g(x, t) = A [U(x + \lambda/2 - vt) - U(x - \lambda/2 - vt)] \sin (kx - \omega t)$. This new expression satisfies d'Alembert's equation and describes a "single pulse" sine wave that is only one wave length long. At $t = 0$ the pulse is centered at the origin, and for $t > 0$ the pulse moves to the right with velocity $v = \omega/k$. Applications might include quantum mechanics as well as wave interference phenomena.

10:30AM PSS-8 Suprathermal Electron Pitch Angle Distributions observed from Geosynchronous Orbit. P. PARRISH, H. RASSOUL, AND M. B. MOLDWIN, Dept. Of Physics and space Sciences, Florida Institute of Technology, Melbourne, FL 32901. Plasma data from the Los Alamos National Laboratory geosynchronous satellite 1989-046 were surveyed to determine the variability of the pitch angle distributions (PADs) of the suprathermal electron populations. Suprathermal electrons are generated by the photoionization of the ionosphere and by field aligned currents. Understanding the dynamics of the PADs as a function of geomagnetic activity and local time are important for modeling plasmaspheric refilling. This paper will present the results from a six-month study.

10:45 AM PSS-9 ALEXIS Attitude Solution Optimization. P. FELKER (1,2), J. BLOCH (2), AND J. THEILER (2), (1) Florida Institute of Technology, Dept. of Physics & Space Sciences, 150 W. University Blvd., Melbourne 32901, (2) Los Alamos National Laboratory, Astrophysics & Radiation Measurements Group, P.O. Box 1663, Los Alamos, NM 87545. Overview of an effort to improve the attitude solution for the Array of Low Energy X-ray Imaging Sensors (ALEXIS) satellite. The spacecraft was damaged during launch and consequently requires substantial computer modeling to predict orientation. Efforts were made to diagnose and eliminate small but significant errors in the computer generated attitude solution. Research supported by the United States Department of Energy and Los Alamos National Laboratory.

11:00AM PSS-10 Plasmasheet and plasmasphere overlap observed at geosynchronous orbit. C. BREGLIA, M. B. MOLDWIN, AND H. RASSOUL, Dept. of Physics and Space Sciences, Florida Institute of Technology, Melbourne, FL 32901. Plasma data from the Los Alamos National Laboratory geosynchronous satellite 1989-046 were surveyed for intervals when the high energy electron plasmasheet was observed simultaneously with the low energy ion plasmasphere. To first order these regions of the inner magnetosphere do not overlap due to the different drift paths that these plasma regimes generally are found. However, during times of rapid reconfigurations of the Earth's magnetic field, these two plasma regimes occationally can be observed simultaneously. This study describes the characteristics of when the overlap occurs as a function of local time, geomagnetic activity, and substorm phase.

11:15 AM PSS 11 Ranges of Monotone Operators in Banach Spaces. A. G. KARTSATOS, Department of Mathematics, University of South Florida, Tampa 33620-5700. We study the existence of zeros and other range properties of maximal monotone or demicontinuous monotone operators mapping subsets of a Banach space into its dual space. In particular, we show that the existence of a zero of a maximal monotone operator is equivalent to a certain asymptotic behavior of its resolvents or its Yosida resolvents. Another result is given which shows that the existence of a zero of a demicontinuous monotone operator T in an open set G is equivalent to the operator T satisfying a Leray-Schauder-type condition on the boundary of G. In addition, we provide sufficient conditions for a pathwise connected set to lie in the range of a maximal monotone operator. Finally, we show that NirenbergÆs problem has an affirmative answer if the operator T in question has a monotone-type property. Namely, an operator T mapping a Hilbert space H into itself is surjective if it is continuous, expansive and

T+qI is monotone, where q is a positive constant in [0,1) and I is the identity operator on H.

11:30 AM , ROOM 204 in Classroom Bldg.
SECTION MEETING: PHYSICAL AND SPACE SCIENCES
Mark Moldwin, Florida Institute of Technology, Presiding

FLORIDA COMMITTEE ON RARE AND ENDANGERED PLANT AND ANIMALS

FRIDAY, 2:15 PM, ROOM 204 in Classroom Bldg.
Rosemarie Mulholland, Florida Park Service, Presiding

2:15PM REB-1 Relocating Central Florida Bats: Can it be Done? LAURA S. FINN, University of Central Florida, Orlando 32816. Attempts to physically relocate bats from buildings to bat houses have met with limited success. Most successful attempts involve bat houses placed directly on the building that housed the original roost. Two experiments in central Florida have added optimism to the problem of removing bats from buildings. In one experiment a mixed colony of *Tadarida brasiliensis cynocephala* and *Nycticeius humeralis* were evicted from a community college in Sanford, FL, and relocated to a set of bat houses ¼ mile from the original roost. The other experiment involved moving a bat house, occupied by a maternity colony of both species, 5 miles from the original site. Methods involved, results, and thoughts for future work will be discussed.

2:30PM REB-2 A Study of the Endangered Yellow-Apple Cactus, *Cereus gracilis* var. *aboriginum*, Longboat Key, Florida. JESSA FISHER, New College, Environmental Studies Program, 5700 North Tamiami Trail, Sarasota 34243. The habitat of this cactus is described, including an in-depth assessment of surrounding flora, with special attention to the dominant tree species, southern red cedar, *Juniperus silicicola*. Blooming and fruiting times are recorded, and all species are identified and mounted. A detailed map of the 4.5 acre hammock describes the area and shows exact locations of all *Cereus* individuals. Each cactus is measured, tagged, and any insect/animal-plant interactions are noted, particularly concerning pollination and dispersal of seeds. The evolutionary history of the cactus is discussed, comparing it with other members of the genus. The delicate relationships between cactus and cedar and other plant members of the habitat are reflected upon and analyzed. The paper concludes with a recommendation for the continued existence and well-being of this cactus.

2:45PM REB-3 Habitat Specificity of the Hand Fern *Ophioglossum palmatum* L. (Ophioglossaceae) in Central Florida. KEITH E. FISHER, Florida Park Service, Tosohatchee State Reserve, 3365 Taylor Creek Road, Christmas 32709. Physiognomic characteristics of hand fern habitat for six central Florida populations is documented. Fern host tree distribution on a landscape scale is evaluated using GPS/GIS technology. Hand fern site specificity on host trees is described. Information presented focuses on management implications for this endangered species on public lands. Effects of management activities on public lands (prescribed burning, wetlands restoration, and facilities construction) are discussed.

3:00PM REB-4 Floristics and vegetation of Topsail Hill, Deer Lake and environs, Walton County, Florida. ROBIN B. HUCK AND PAMELA MURPHY, Dept. of Environmental Protection, Panama City 32408. A diverse landscape of interdunal lakes, beach-dunes, pine flatwoods, sand pine scrub, sandhills, blackwater streams and depressional ponds are habitats for a diverse flora in coastal panhandle Florida in Walton County. Nearly 250 species of vascular plants, some rare and endemic, were collected and identified in a recent inventory of these new State lands. Ecotonal areas surrounding cypress domes are occupied by, among others, insectivorous plants, and Curtiss' sandgrass (*Calamovilfa curtissii*). Growth habit of the latter is similar to the cutthroat grass (*Panicum abscissum*) seeps in central Florida. Tulip tree (*Liriodendron tulipifera*) was discovered on the edge of the blackwater streams. A radiation of species in genera such as *Rhexia, Rhynchospora, Chrysopsis, Polygonella* and *Polygala* is found here.

3:15PM REB-5 Wildlife Management. I. M. REINPOLDT, Pinellas County Utilities, 14 South Fort Harrison Avenue, Clearwater 34616. Pinellas County Utilities' Cross Bar wellfield has undergone a transformation to convert the property from its principal usage of wellfield to a balanced wildlife management regime of wellfield, timber operation, wildlife management, and cattle ranching. The project identifies wildlife enhancement opportunities compatible with timber practices, ranching, and wellfield operations. Initial findings indicate wellfield areas may provide an excellent forum for the coexistence of listed and non listed species, silviculture, wildlife enhancement, cattle production, and public supply wellfield operations.

3:30PM REB-6 Florida Scrub-Jays of the Wekiva River Basin. PARKS E. SMALL, Florida Park Service, 1800 Wekiwa Circle, Apopka 32712. Beginning in 1992 publicly managed lands within the Wekiva River Basin (Wekiwa Springs State Park, Rock Springs Run State Reserve, Lower Wekiva River State Preserve, and Seminole State Forest) were initially surveyed for the presence of Florida Scrub-jays. In an effort to better understand site specific habitat requirements jays were individually marked for further study; habitat parameters were surveyed; and reproductive efforts monitored. Data on population and habitat structure, reproductive success, and dispersal will be presented.

3:45PM REB-7 Nesting Survey of the Threatened Least Tern in Southeast Florida. R. ZAMBRANO, Florida Game and Fresh Water Fish Commission, 551 N. Military Trail, West Palm Beach 33415. Six counties in southeast Florida were surveyed for nesting least terns (*Sterna antillarum*). Previously documented sites in our Wildlife Occurrences Database were reexamined, and new sites obtained from other wildlife agencies and organizations were also surveyed. We estimated a minimum of 1,437 breeding pairs in 29 active colonies. However, the majority (93%) of the active colonies found were gravel and tar roof-top sites, the rest were ground nesting colonies. The shift from ground nesting sites to roofs is probably a direct result of intense beach front development and human recreational activities in this highly urbanized area. Colony turnover was also very high. Sixty-five percent of previously documented sites (n=26) were no longer active and 20 new sites were found. Construction, human disturbance, and roof repairs were suspected causes of abandonment of some of these colonies. Black skimmers (*Rynchops niger*), a Species of Special Concern, were also found nesting on 6 of the least tern roof colonies.

4:00 PM, R OOM 204 in Classroom Bldg.
SECTION MEETING: FLORIDA COMMITTEE ON RARE AND ENDANGERED PLANTS AND ANIMALS
Rosemarie Mulholland, Florida Park Service, Presiding

SCIENCE TEACHING

FRIDAY, 9:00AM, ROOM 101 in Classroom Bldg.
SESSION A
Jan Ems-Wilson, Valencia Community College, Presiding

9:00AM TCH-1 Tricks of the Trade: Professing Biology. SUSAN MATTHEWS AND DAVID SHELDON, Valencia Community College, 1800 Kirkman Rd., Orlando, FL 32811. Techniques will be presented which will assist teachers in establishing positive classroom atmospheres, increase student retention and increase learning, These techniques include ice-breaking, game-playing, dramatization of concepts, use of annotations. Journals, writing exercises, student presentations and co-operative learning.

9:15AM TCH-2 Reinforcing Concepts of Molecular Biology by Teaching Applied Skills and Applications in the Biology Laboratory. THOMAS P. ARNOLD, SUSAN MATHEWS, JAN EMS-WILSON and FRANCES A. FRIERSON, Valencia Community College, Dept. of Science and Technology, West Campus, Orlando, Florida 32802. The following biology labs have been developed and are used to demonstrate in increments the dynamics of gene expression and acquaint students with the technologies used to study macromolecules *in vitro:*

I Proteins as Macromolecules; Native protein electrophoresis.
II The consequences of genetic variation on protein structure/function.
III DNA as a Macromolecule: Restriction Mapping.
IV Manipulation of DNA: Plasmids as vectors.

With this exposure biology and other science majors will be better able to comprehend these rapidly developing technologies. Those with an interest is these disciplines can graduate from community colleges and carry with them the knowledge and skills to transfer to a senior institution better prepared to interact in the research and academic settings.

9:30AM TCH-3 The Florida Biodiversity Research Project: A BCC Summer Program for High School Students. J. R. YOUNT, Brevard community College, 1311 North US 1, Titusville, FL 32796. The 1996 Florida Biodiversity Research Project, funded by the Governor's Summer Program and BCC, was was a 14-day program designed to encourage an understanding of the importance and complexity of Florida's biodiversity and the responsibiltiy of humans to establish an environmental ethic in its regard. Outstanding high school students performed college-level research and analysis while participating in interest-generating outdoor activities in local forests and streams. Topics included techniques in ecological biodiversity studies, including survey design, sampling methods, lab analysis of water, soil, bacteria, and plankton, light and electron microscope techniques, and data recording, retrieval, and interpretation. Perspectives on environmental planning were explored based on local wastewater treatment renovations and county land planning activities. Representative from the University of Central Florida, the Brevard County Environmentally Endangered Lands Program, the Enchanted Forest Sanctuary, and Tosohatchee State Reserve were key participants.

9:45AM TCH-4 Supplemental Instruction and Its Impact on Participating Freshman Biology Students. C. N. DUNSTAN AND E. T. HAYS, SNHS, Barry University, 11300 NE Second Ave., Miami 33161. In recent years student retention levels have become a major concern for colleges and universities nationwide. As a result of many years of analysis, the SNHS at Barry University has identified the two most important factors affecting its student retention levels. The crucial determinants include the student's first semester cumulative GPA and the student's success in their first semester biology course. One response of the SNHS to reduce attrition levels has been to institute supplemental instruction (SI). The aim of SI is to enhance the comprehension level of and familiarity with course work taught in the first semester biology course. A summary of the instructors experiences along with student feedback will be presented. Student evaluations of the program suggest that SI was beneficial and recommend that SI be continued in freshman and more advanced courses.

10:AM BREAK

10:15AM TCH-5 Predictors of Success in Undergraduate Biology. E.T. HAYS AND J.M. MONTAGUE, SNHS, Barry University, 11300 NE Second Avenue, Miami 33161. What are the factors that best predict early success and retention of undergraduate biology majors at a small university with a very diverse student population? Whereas Group Assessment of Learning Techniques (GALT) scores were found to be unreliable, high school GPA's, math and verbal SAT's, and National Association of Biology Teachers exam scores had more reliable predictive value both for academic success in the first year of college as well as in the retention of the students. On the basis of these predictors, support programs can be developed to enhance both the academic performance and retention of at-risk students.

10:30AM TCH-6 Muscles of the Hip: An Interactive Module for Use in Anatomy Classes. M. K. DUNSON (1) AND R. MARTIN (2), (1) Dept. of Biology, and (2) Instruc. Design Spec., Penn. State Univ., DuBois Campus, DuBois, PA 15801. We designed exercises for hip muscles and incorporated them into the computer program "Authorware." We modified anterior and posterior views of the skeleton from "A.D.A.M. Standard" and used isolated muscles from "A.D.A.M. Comprehensive". Our training module includes four exercises designed to convey an understanding of 15 hip muscles: a) click and drag names of skeletal features that serve as muscle attachment sites to their correct skeletal position, b) click and drag names of hip muscles to the correct muscle, c) click on correct origin, then insertion, and muscle then appears in its proper location, d) drag names of muscles to one of four action categories. Student response has been enthusiastic.

10:45AM TCH-7 Determining Environmental Competencies for the 21st Century Workforce. I.M. REINPOLDT, Pinellas County Utilities, 14 South Fort Harrison Avenue, Clearwater, Florida 34616. Local educational providers do not address the student's interest in career because they do not provide the appropriate knowledge, skills and typical information required for entry level employment. This project addresses workforce needs by developing an environmental curriculum which will provide the practical knowledge, skills and typical information needed to gain entry in the environmental field. Effective partnership strategies, determining information about employer expectations and needed competencies, and seeking the input from experts in the environmental field using a focus group process to involve almost 100 different environmental professionals will be discussed.

11:00AM TCH-8 The Bridges Grant Program. JAN EMS-WILSON, FRANCES FRIERSON, AND MICHAEL FERRETTI, Valencia Community College, 1800 S. Kirkman Rd., Orlando, FL 32811. The Bridges Grant Program, funded by the National Science Foundation and Valencia Community College, is a one-year iniative which will facilitate the success of targeted students in the biological and physical science programs. Selected Apopka High School and Valencia students will take part in a 10-week research and lab class which is used to demonstrate and acquaint students with the technologies used to study macromolecules in vitro. Topics include proteins as macromolecules, protein electrophoresis, consequences of genetic variation on protein structure, DNA and restriction mapping and manipulation of DNA. A peer mentoring program and gender equity/industry speakers will focus on topics such as strategies to facilitate the successful social and academic transitions of female students, leading to career exploration and planning.

11:15 AM, ROOM 101
SECTION MEETING: SCIENCE TEACHING
Jan Ems-Wislon, Valencia Community College, Presiding

SESSION B: SYMPOSIUM ON "THE SUNSHINE STATE STANDARDS AND THEIR IMPACT ON THE INTRODUCTORY COLLEGE SCIENCE COURSE"
Friday, 2:00 PM, ROOM 101 IN CLASSROOM BUIDLING
Gerry Meisels, Univ. of south Florida, Coalition for Science Literacy

SYMPOSIUM AGENDA

2:00PM TCHSYMP-1 Introduction & Overview, DR. GERRY MEISELS, Univ. of South Florida, Coalition for Science Literacy

2:30 PM TCHSYMP-2 The Sunshine State Standards in Science, Dr. CHARLES MOTT, St. Petersburg Junior College, Dept. of Earth Science

3:00PM TCHSYMP-3 Laying the Foundation for Change: the 1995 Regional Workshop, DR. HENRY MUSHINSKY, Univ. of South Florida, Dept. of Biology

3:30 PM TCHSYMP-4 Future Background of High School Graduates and Changes in Competencies Required of New Teachers, NANCY MARSH, Hillsborough Co. School System

4:00 PM TCHSYMP-5 Developing Regional Agreement on Principles of a New Course, DR. BOB POTTER, Univ. of South Florida, Dept. of Chemistry

4:30 PM TCHSYMP-6 Specification for an Integrated, Modular Course, DR. DONNA HENRY, Florida Gulf Coast University

4:55 PM Concluding Remarks, DR. GERRY MEISELS

SOCIAL SCIENCES

FRIDAY, 2:15 PM, ROOM 211 in Classroom Bldg.
Maribeth Durst, Saint Leo College, Presiding

2: 15 PM SOC-1 Harm Reduction for Alcohol-Related Problems among College Students: A Replication and Extension. C. CRONIN, Saint Leo College, St Leo 33574. Two studies evaluated the efficacy of "explicit priming" for reducing alcohol-related problems among college students during discreet, high risk periods. The "explicit priming" task involved asking students to predict the type and frequency of alcohol-related problems they expected to experience during the upcoming high risk period. The first study used 110 university students (53 males and 57 females) at a university in South Australia. The second study used 236 college students enrolled at two liberal arts colleges in Kentucky and Florida. Both studies demonstrated a significant reduction in alcohol-related problems among students who were explicitly primed prior to the high risk period.

2:30 PM SOC-2 Expectations of the Elderly Regarding Counseling. C.M. CIANCI, Saint Leo College, St. Leo 33574. The present study looked at elderly person's expectations regarding counseling. Previous research has suggested that elderly individuals are resistant to counseling. Seventy-eight individuals between the ages of 55 and 75 completed the 73 item Expectations About Counseling -Brief Form (EAC-B) questionnaire. The EAC-B is comprised of 17 scales reflecting four common expectation factors related to counseling. Scores on the EAC-B were consistent with previous studies. However, participants' responses significantly varied based on sex, education level and prior counseling experience. Results are discussed in terms of strategies for educating specific segments of the elderly population regarding counseling.

2:45 PM SOC-3 A Comparative Cross-Discipline Study of Traditional and Nontraditional College Students. SUSAN KINSELLA, Dept. Of Social Work, P.O. Box 6665, Saint Leo College, St. Leo 33574. Nontraditional College Students have been the focus of several recent investigations. Defined as over 24 years of age or returning to school after a break in their education (Hirschorn, 1988), nontraditional students make up almost half of the undergraduate students enrolled in college today. Nontraditional students are often married, work, and have childrenso returning to school means making a significant life change (Harouff, 1996). Many schools are now beginning to address the needs of the nontraditional studentby offering special adult student services and nontraditional student associations (Boben, 1996). In this recent comparative study, students on one Florida campus were examined to determine what disciplines nontraditional students were selecting. A comparison of traditional and nontraditional students was made regarding age, gender, marital status, enrollment status, number of dependents, and types of responsibilities held outside of the educational environment. Implications for student support services and student adjustment are discussed.

3:00 PM SOC-4 The Role of Stimulus Comparison in an Olfactory Classical Conditioning Discrimination Task in Neonatal Rats. R. G. BRYAN, Dept. of Psychology, Saint Leo College, St. Leo, FL 33574. Young rats exposed to an odor (CS+) paired with an unconditioned stimulus (US) do not easily form an association unless they are exposed to a second odor (CS-) paired with absence of the US. The "stimulus selection" explanation of this "CS- Effect" is that shifts from CS- to CS+ calls attention to the CS+ facilitating learning the CS+- US association. One hundred-sixty 7 to 8 day old albino rats were exposed to one odor (CS+) with a sibling (US) and a second odor (CS-) without the US. As predicted by the "stimulus selection" hypothesis animals exposed to CS- before CS+ learned better than those presented with CS- after CS+. A one-minute separation between CS presentations did not disrupt learning as would be predicted. Longer separations may be required to produce measurable disruption.

3:15 PM SOC-5 A Survey of the Homeless Population in Pasco County. D. McILVAINE, 5836 10th Ave. New Port Richey 34652. "... Experts have been unable to agree on how many homeless people there are and on whether or not the total is rising. Estimates range from a few hundred thousand to as many as several million. Lack of consensus on this basic policy issue is understandable; individuals and families without a permanent address are often hard to find." (Worsnop, Richard L. 1996., Helping the Homeless. C Q Researcher. 6 (4) 75). The unique problems related to identifying the homeless population in Pasco County along with implementing an accurate survey is examined. Demographics, survey design, methodology , outcome analysis and implications for the future are reviewed.

3:30 PM, ROOM 211
SECTION MEETING: SOCIAL SCIENCES
Maribeth Durst, Saint Leo College, Presiding

URBAN AND REGIONAL PLANNING

FRIDAY, 2:15PM, ROOM 102 in Classroom Bldg.
Richard March, South Florida Water Management District, Presiding

2:15PM URP-1 Funding Water Supply and Environmental Restoration and Enhancement Programs in the South Florida Water Management District. JANE KIRKER BUCCA and RICHARD A. MARCH, South Florida Water Management District. Recent legislation has expanded the range of water supply and environmental enhancement projects which the South Florida Water Management District is obligated to undertake. The District is limited both statutorily and constitutionally in the millage rate which it can charge. In this paper alternative funding sources are identified, the revenue generating potential of each source is examined, and pluses and minuses are identified. Opportunities and potential pitfalls of cost-sharing arrangements with other public (and private) entities will be discussed. The examples presented in this paper will be extrapolated to other agencies of the state, and conclusions will be drawn regarding funding of public services in an era of scarce public funds.

2:30PM URP-2 Roles and perceptions of planning professionals in a resource management agency. SUSAN A. MASON and RICHARD A. MARCH, South Florida Water Management District. In this paper, the role of planners in the South Florida Water Management District will be examined. Implications of having planners dispersed to multi-disciplinary organizational units will be discussed. Problems facing planning professionals in defining and communicating their role in what has traditionally been an engineering and natural science-oriented agency will be discussed. Implications will be drawn as to how planners can more effectively function in a multi-disciplinary resource management agency.

2:45PM URP-3 ARIMA forecasting of Public Water Supply Pumpages for the counties and planning areas of the South Florida Water Management District. RICHARD L. MARELLA, U. S. Geological Survey, Tallahassee, Florida and RICHARD A. MARCH, South Florida Water Management District. Autoregressive Integrated Moving Average modeling is used to forecast county level public water supply pumpages in the sixteen counties wholly or partially in the South Florida Water Management District. These pumpages will be aggregated for the four major planning areas of the District (Upper East Coast, Lower East Coast, Lower West Coast and Kissimmee areas) and the results for the four areas compared. These projections will be compared to otherr planning projections from Water Management District Water Supply Plans and local government comprehensive plans.

3:00PM, ROOM 102
SECTION MEETING: URBAN AND REGIONAL PLANNING
Richard March, South Florida Water Management District, Presiding

NOTES

AUTHOR INDEX

NAME, PAGE
ALLEN, MB., 1
AFIOUNI, G., 20
AGARWAL, S., 9
ARNOLD, TP., 39
ARTHUR, JD., 28, 31
BAKER, EW., 27
BANCROFT, GT., 15
BATTS, M., 15
BELLABE, RK., 9
BELSON, MS., 14
BENSON, RF., 18, 19
BIERHANZL, EJ., 10
BINGHAM, SM., 12
BISNAUTH, LD., 19
BLANCHARD, G., 7
BLANCHARD, GA., 26
BLOCH, J., 35
BRAMAN, RS., 25
BREGLIA, C., 35
BROWN, RC., 26
BRUDERLY, D., 16
BRYAN, RG., 43
BUONI, FB., 17
BUCCA, JK., 44
CAPECE, JC., 15
CARDINALE, TC., 26
CARPENTER, RK., 18
CIANCI, CM., 42
CLAUSEN, CA., 19, 20
CLAUSEN, CM., 19
CORREA, S., 9
CRONIN, C., 42
CUTWA, MM., 13
daSILVA, SS., 17
DELAMO, D., 12
DONOGHUE, JF., 30
DOWNEY, LA., 23

NAME, PAGE
DUNSON, MK., 40
DUNSON, WA., 25
DUNSTON, CN., 39
EMS-WILSON, J., 39, 41
EVANS, III, WL., 29
FARAGO, M., 25
FALABELLA, V., 12
FELKER, P., 35
FERIALI, K., 5
FERRETTI, M., 41
FINN, LS., 36
FISHER, J., 36
FISHER, KE., 37
FORSELL, H., 33
FOSS, WM., 23
FRIERSON, FA., 39, 41
GALLARDO, M-T., 24
GARRIDO, G., 17
GEIGER, CL., 20
GONZALEZ, FJ., 23
GOODE, B., 32
GRABE, SA., 26
GUBBLES, TL., 29
GUIDRY, J., 19
GUTIERREZ, OM., 3
HABERFELD, JL., 28
HAKEY, JE., 22
HAMILL, BA., 10
HARWOOD, VJ., 9
HAYS, ET., 39, 40
HENNEBENG, M., 2
HENRY, D., 42
HICKMAN, H., 34
HOENSTINE, R., 30
HUCK, RB., 37
HUGHES, D., 4
HURLEY, J., 33

ISCAN, MY. , 1, 2, 6
JACOB, R., 5
KALMANSON, P., 33
KARLEN, J., 7
KARTSATOS, AG., 35
KELLEY, M., 28
KESSEL, MH., 1, 6
KING, CA., 2
KINSELLA, S., 43
KONAKLIEVA, MI., 22, 23
LABOS, N., 4
LAMBIE, J., 17
LAO. N., 20
LEWIS, G., 9
LEWIS, M., 12
LI, YC., 17
LIE, J., 27
LIESMAN, JM., 13
LOITZ, JW., 27
LOTH, SR., 2
LOUDA, JW., 21, 27
LOVEJOY, DW., 30
LYONS, W., 7
MANNING, TJ., 20
MANTOVANI, JG., 33
MARCH, RA., 44, 45
MARELLA, RL., 45
MARQUARDT, WH., 7
MARTIN, BB., 18, 24, 25
MARTIN, DF., 18, 19, 22, 24, 25
MARTIN, R., 40
MARI, F., 21
MARSH, N., 42
MASLIAH, LR., 32
MASON, SA., 44
MATTHEWS, S., 38, 39
MATE-NANKERVIS, JF., 13
MATE-NANKERVIS, S., 9
McILVAINE, D., 43
MEISELS, G., 41
MELENDEZ, O., 33
MESADIEU, M., 8
MEYERS, RH., 21
MILINKOVICH, OJ., 10
MOLDWIN, MB., 32, 34, 35
MONTAGUE, JM ., 40
MONTAGUE, JR., 8, 9
MORALES, A., 8, 9
MOTT, C., 41
MOZAFFARI, M., 15
MURPHY, P., 37
MUSHINSKY, H., 41
NEGRON, RE., 22
NELSON, JK., 21
NGO, L., 34
NGUYEN, T., 34
NORWOOD, Jr, J., 32
OBIN, JN., 1
O'TOOLE, R., 9
PALACIOS, D., 33
PALMER, JW., 26
PARADISE, CP., 25
PARRISH, P., 34
PEREZ, E., 18, 19, 24
PEREZ, S., 26
PERKINS, T., 7
POTTER, R., 42
PRATHER, DM., 21
PRINDLE, V., 24
PUNZO, F., 14
RAFFAELLE, RP., 33
RAGLAND, PC., 30
RANDALL, JL., 11
RASSOUL, H., 34, 35
RAYMOND, K., 34
REINHART, D., 20
REINPOLDT, IM., 37, 40
ROBERT, JM., 22
ROSS, CI., 21
RUDINSKY, M., 9
RUDNICK, DT., 27
RUIZ, N., 20
SANBORN, AF., 9, 13
SAWYERS, W., 24
SELKA, Jr., SL., 4
SHELDON, D., 38

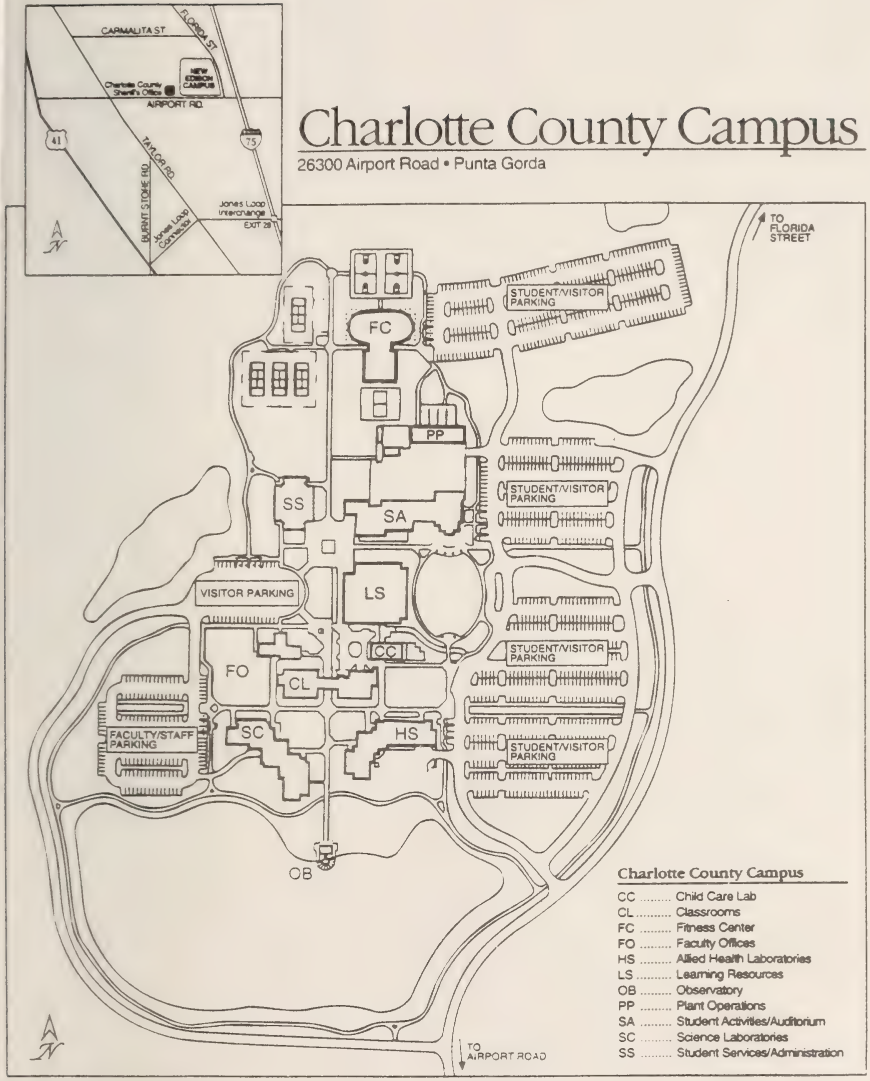
SHI, H., 22, 23
SILVER, TM., 15
SMALL, PE., 37
SMITH, AA., 15
STANCZYK, SM., 21
STOOK, Jr., K., 9
SWAIN, HM., 11
THEILER, J., 35
TEITELBAUM., N., 3
THOMPSPN, K., 34
THORNTON, I., 25
TOY, P., 20
TRIMBLE, CA., 30
TURINGAN, RG., 13
TURNER, RL., 11
TUROS, E., 22, 23
VANFLEET, R., 25
WAGNER, V., 9
WALKER, KJ., 6
WANG, C., 18, 19, 22
WHARTON, BR., 12
WHEELER, RJ., 6
WHITMAN, D., 29
WILLIAMS, LM., 8
WILLIAMS, SL., 11
YORK, DS., 14, 15
YOUNT, JR., 39
ZAHORCAK, AJ., 11
ZAMBRANO, R., 38
ZHENG, J., 27

NOTES

NOTES

Charlotte County Campus

26300 Airport Road • Punta Gorda


CARMALITA ST
FLORIDA ST
NEW EDISON CAMPUS
Charlotte County Sheriff's Office
AIRPORT RD.
41
75
TAYLOR RD.
BURNT STORE RD.
Jones Loop Connector
Jones Loop Interchange
EXIT 28
N
TO FLORIDA STREET
STUDENT/VISITOR PARKING
FC
PP
SS
SA
VISITOR PARKING
LS
CC
FO
CL
SC
HS
FACULTY/STAFF PARKING
OB
TO AIRPORT ROAD
Charlotte County Campus
CC .... Child Care Lab
CL .... Classrooms
FC .... Fitness Center
FO .... Faculty Offices
HS .... Allied Health Laboratories
LS .... Learning Resources
OB .... Observatory
PP .... Plant Operations
SA .... Student Activities/Auditorium
SC .... Science Laboratories
SS .... Student Services/Administration

From the North: Take exit 29 from I75, then west into Punta Gorda on Hwy 17. Turn left on Hwy 41 to Taylor Road. Head southeast on Taylor Road to Airport Road. Turn left on Airport Road. The campus will be on your left.

From the South: Take exit 28 from I75, then west on Jones Loop Road to Taylor Road. Turn right on Taylor Road to Airport Road. Turn right on Airport Road. The campus will be on your left.

Note: There is no intersection at I75 and Airport Road.

Published By:
FLORIDA ACADEMY OF SCIENCES
P. O. BOX 033012
INDIALANTIC, FL 32003-0012

U.S. Postage
PAID
Permit #26
Melbourne, FL

Florida Academy of Sciences, Inc.
P.O. Box 033012
Indialantic, Florida 32903-0012

Nonprofit Org.
U.S. Postage
PAID
Permit No. 440
Lawrence, Kansas

** MIXED ADC
01434 UFX 0005
Smithsonian Institution
Main Library--Acquisitions Department
NHB Room 25
Serials Exchange
Washington DC 20560

MOVING?

DO NOT MISS AN ISSUE . . . .

Return this sheet to us immediately with address label attached.
Clearly print new address and telephone number here:

Telephone: (______) ____________ B H
Circle B for Business; H for Home

SMITHSONIAN INSTITUTION LIBRARIES
3 9088 01354 2055